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2

Peter D Riley

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To Margaret and Brian

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Contents

Preface

To the student

It is the second year of your science course but before you begin, think back to last year. What do you particularly remember about the course? Was it learning how to use the Bunsen burner or the microscope? Maybe you enjoyed the work on rocks and fossils, sampling a habitat or the activities on forces and motion.

All scientists have favourite areas of study. Carl Linnaeus, in Sweden, was interested in classifying living things. Louis Pasteur, in France, made investigations on microorganisms. Shen Kuo, in China, examined rocks and fossils to try and explain the landscape. Al Beruni, in Persia, considered by many to be one of the greatest scientists of the Islamic world, studied a very wide range of topics from the stars in space to the rocks on Earth beneath his feet. How would *you* describe yourself? Can *you* describe yourself in a similar way – your name, where you live and what scientific subjects interest you?

While it is important to have a particular interest in science, it is also very important at this stage to study a wide range of topics, as Al Beruni did. Other scientists such as Galileo, who lived in Italy, did this too. He studied forces, motion, magnetism, stars, planets and the structure of the Solar System. This year, as you learn more about biology, chemistry and physics, you should take an interest in them all to build up a broad scientific knowledge as you refine your Scientific Enquiry skills. You should also look back at the work you did last year and look at how you can link it together. For example, your work on cells last year is relevant to your work on the body and health this year and your work on friction and air resistance will help you with your studies on speed.

Cambridge Checkpoint Science covers the requirements of your examinations in a way that I hope will help you build up your scientific knowledge and your Scientific Enquiry skills. The questions are set to help you extract information from what you read and see, and to help you think more deeply about each chapter in the book. Some questions are set so you can discuss your ideas with others and sometimes develop a point of view on different scientific issues. This should help you in the future when new scientific issues, which are as yet unknown, affect your life.

The building up of scientific knowledge and Scientific Enquiry skills are enjoyed so much by many people that they take up a career in science. Perhaps *Checkpoint Science 2* might help to take you on one more step towards a career in science too.

To the teacher

Checkpoint Science 2 has been developed from *Checkpoint Biology*, *Checkpoint Chemistry* and *Checkpoint Physics* to cover the requirements of the Cambridge Checkpoint Tests and other equivalent junior secondary science courses. It also has three further aims:

- to help students become more scientifically literate by encouraging them to examine the information in the text and illustrations in order to answer questions about it in a variety of ways
- to encourage students to talk together about what they have read
- to present science as a human activity by considering the development of scientific ideas from the earliest times to the present day.

The student's book begins with a chapter called *Science skills and knowledge* where the students are challenged to define science. They then briefly review some of the areas of skills and knowledge they studied last year before going on to examine the requirements for Scientific Enquiry for stage 8 of the Cambridge Secondary 1 Science Curriculum Framework. This is followed by looking in greater detail at three new requirements: creative thinking, variables and making simple calculations. The chapter ends by providing the students with opportunities to exercise their Scientific Enquiry skills in two investigations.

The following chapters are arranged in sections with Chapters 1–7 addressing the learning requirements for biology stage 8, Chapters 8–12 addressing the learning requirements for chemistry stage 8 and Chapters 13–16 addressing the learning requirements for physics stage 8 of the Cambridge Secondary 1 Science Curriculum Framework.

The student's book is supported by a teacher's resource book that provides answers to all the questions in the student's book – those in the body of the chapter and those that occur as end of chapter questions. Each chapter is supported by a chapter in the teacher's resource book which features a summary, definitions of words that ESL students may have difficulty with, chapter notes providing additional information and suggestions, a curriculum framework reference table, practical activities (some of which can be used for assessing Scientific Enquiry skills), homework activities, and a 'lesson ideas' section integrating the practical activities and homework activities, and two Practice Tests with marking guidance. A complete glossary of scientific words can be found at the back of the book. This can be given to students to help build up a scientific vocabulary.

Peter D Riley
August 2011

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Science skills and knowledge

- Thinking about ideas to test
- Planning investigations
- Collecting evidence
- Presenting evidence
- Considering the evidence
- Creative thinking
- Making simple calculations

If somebody asked you 'What is science?' How would you reply?

The chances are you might say that it is about finding things out and it is a huge store of knowledge about our world and the way that it works. We divide this knowledge into three big topics: biology, chemistry and physics. If these are your answers then you are correct but how are you developing as a scientist?

Which of these science skills have you learnt?

- Measuring a force

Figure 1 Using a spring balance

- Using a Bunsen burner

Figure 2 Heating a liquid

- Testing for acids and alkalis

Figure 3 Using pH indicator solution

- Observing with a microscope

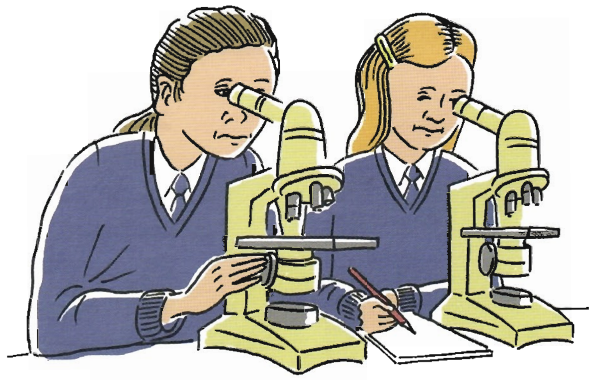


Figure 4 Using microscopes

What do you know about these areas of knowledge?

- The classification of living things

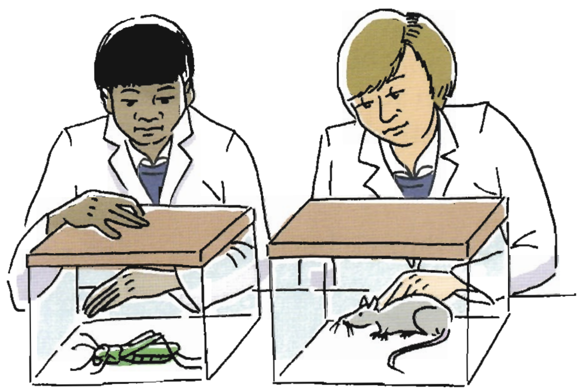


Figure 5 Looking at different types of animals

- The different kinds of rocks

Figure 6 Looking at a collection of rocks

- The different forms of energy and how they change

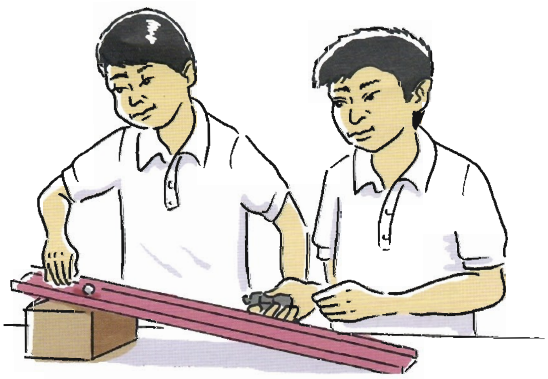


Figure 7 Releasing a ball down a ramp

- Stars and planets

Figure 8 Looking at the night sky

Scientific enquiry

The store of scientific knowledge has been built up by making scientific enquiries. A scientific enquiry is divided into four stages and in each stage there are two or more scientific activities as shown below.

Stage 1: Considering ideas and evidence

- Discuss the importance of developing empirical questions which can be investigated, collect evidence, develop explanations and use creative thinking.
- Test predictions with reference to evidence gained.

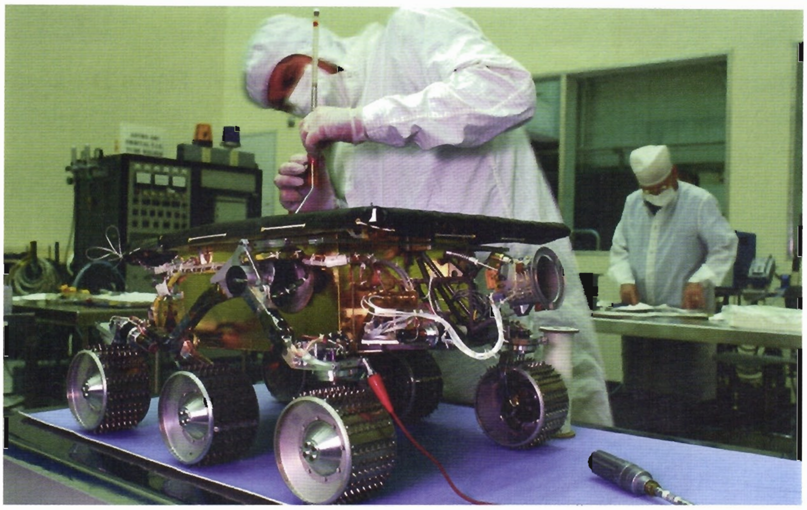


Figure 9 After researching the conditions on Mars that have been discovered by previous space probes, scientists think up new investigations and prepare apparatus for the next space mission.

Stage 2: Planning

- Select ideas and turn them into a form that can be tested.
- Plan investigations to test ideas.
- Identify important **variables** (see page 7) and choose which variables to change, control and measure.
- Make predictions using scientific knowledge and understanding.

Stage 3: Obtaining and presenting evidence

- Take appropriately accurate measurements.
- Use a range of equipment correctly.
- Discuss and control risks to themselves and others.
- Present results as appropriate in tables and graphs.

Figure 10 Scientists select ideas to test from the ones they have thought up.

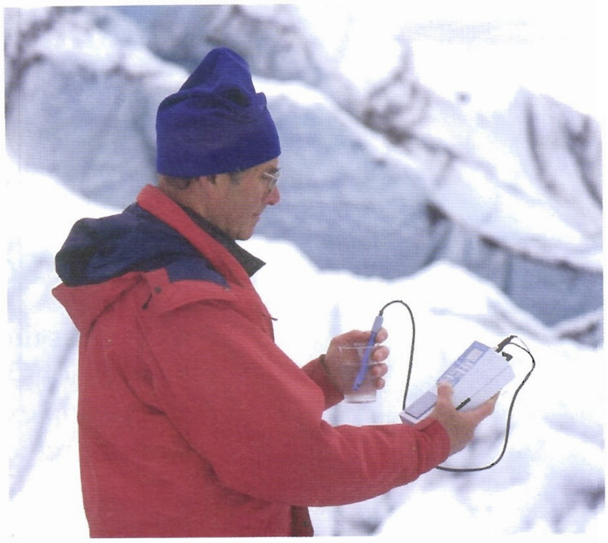


Figure 11 Accurate measurements are taken to provide data for an investigation.

Figure 12 Scientists working in different parts of the world meet up at seminars to present and discuss the results of their investigations. These meetings often help the scientists to think creatively and devise new investigations to carry out.

Stage 4: Considering evidence and approach

- Make simple calculations.
- Identify trends and patterns in results (**correlations**).
- Compare results with predictions.
- Identify anomalous results and suggest improvements to investigations.
- Interpret qualitative data from secondary sources.
- Discuss explanations for results using scientific knowledge and understanding and communicate this.
- Present results to others in appropriate ways.

To help you become familiar with these activities there are Scientific Enquiry spotter questions in most chapters of the book. You can identify them with the icon shown here and by the green background to the question boxes. When you find one, turn back to pages 3 and 4 and use the activity list to help you answer.

Creative thinking, variables and calculations

During the course of the year you will have many chances to try all the Scientific Enquiry activities. Many of them build on those in *Checkpoint Science 1* but there are three new features in this book. They are creative thinking, variables and making simple calculations.

Creative thinking

You might think that creative thinking is to do with writing poetry or painting a picture and is to do with arts subjects not science. However, creative thinking is very important in science too as it allows scientists to think freely about a question and come up with lots of suggestions which could be tested. Sometimes it helps them find links between ideas and information and this helps them set up a scientific theory.

To be a creative thinker you need to have lot of things to think about, so the more you research and find out the better your chance of thinking creatively. Imagine that you were given two blocks of different materials and asked to compare them. If you think about the properties of materials which you investigated last year you may come up with this series of tests.

> **1** To begin a creative thinking exercise it is important to get the brain to relax and think about linking things which you would not normally link together. For example, you could begin by thinking about the question if you were a piece of scientific equipment what would you be? Why?

> **2** Which property is being investigated in each of the tests 1 to 6?

1. Bending each block.
2. Scratching the corner of one block on the flat surface of the other to see which makes the deeper mark.
3. Hitting each one with a hammer to see which one is shaped more by the impact.
4. Putting the same amount of water on the top of each block and looking to see whether any goes inside the block.
5. Putting each one in warm water and, after a few minutes, testing whether one feels warmer than the other.
6. Putting each block into a simple electrical circuit with a battery, switch and lamp and finding whether either of them conducts electricity.

All these ideas may come to you from your work last year but how would you find out which block was the shiniest? You may have to think harder.

You could begin by thinking about a source of light to use and conclude that a torch would be the best thing. You could then shine it on the same area of flat surface of each block to make the test fair and see which one shines more.

3 How can you use the measurements to show which block is shinier?

However, in science investigations something is usually measured so how could you measure the shininess?

Your creative thought might flow in the following way.

What happens to light when it reaches a surface? It is reflected; the light shines back.

How could I see if the light shines back? I could put a surface close by and see if it lights up when I shine the torch on the block. If it does, I could move it back until no light is reflected from the surface and measure the distance of the surface from the block.

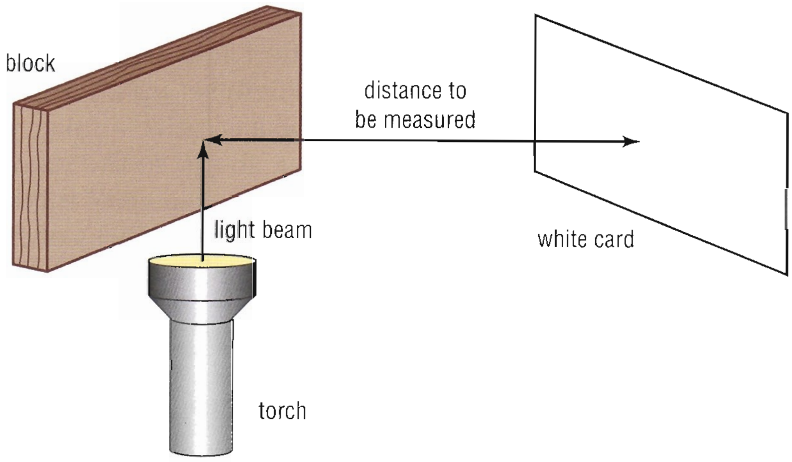


Figure 13 Apparatus for measuring reflection

I could then repeat the test with the second block and compare the distances at which light failed to reach the surface.

> **For discussion**
>
> **Do people memorise facts better in silence or when they listen to music? How can an investigation be carried out? Brainstorm in a group. Then build up an investigation to find out. Make a prediction – then carry out the investigation and present your results and conclusions to the rest of the class.**

Brainstorming

A group of between five and seven people can take part in a creative thinking exercise called brainstorming. A problem is given to the group and everyone makes suggestions about how it could be investigated. It is just an idea-collecting exercise and one person should write down the ideas as they occur. Any idea can be submitted, such as the first idea someone thinks about. It does not matter if it seems silly as it might give someone else another more serious idea. Once a list of suggestions has been collected the brainstorming can be stopped and the group can then select ideas to test.

Variables

Variables are the things that are investigated in a scientific enquiry. Two types of variables are the **independent** variable and the **dependent** variable. The independent variable is the one that the scientist alters in an investigation. The dependent variable is the variable which changes as a result of changing the independent variable. For example, if a scientist wants to find out how temperature affects the growth of a species of plant, the variables feature in the plan for the investigation in the following way.

Three pots of seedlings of the same age are set up in places at different temperatures (the independent variable) and the growth of the seedlings (the dependent variable) is measured every two days.

From this you can see that the growth of the seedlings (the dependent variable) depends on the temperature chosen by the scientist (the independent variable).

Making simple calculations

In many investigations, measurements are made. They are often recorded in a table and then calculations may be performed on them. Here are the steps in a simple investigation about walking.

1 If you walk twenty paces do you always cover the same distance?

2 Walk twenty paces and measure the distance covered with a long tape or metre rule. Repeat twice more.

4 Which step in the walking investigation is an empirical question that can be investigated?

5 Which step is a plan of the investigation?

6 Which activity in 'obtaining and presenting evidence' is taking place in step 3?

7 When someone else tried the investigation the distances covered in each walk were:
Walk 1: 17.3 m
Walk 2: 17.4 m
Walk 3: 17.2 m

a) What was the average distance walked?

b) What was the length of the average pace?

3 Record the measurements.

Walk	1	2	3
Distance covered/m	15.5	15.3	15.7

4 Looking at the results you can see that you do not cover the same distance every time.

5 How much difference is there between the longest distance and the shortest distance?

$15.7 - 15.3 = 0.4\,m$

6 Can the average length of your pace be worked out from the data? Yes: the three distances covered are added together and divided by three to find the average distance covered (A), and then this number is divided by 20 to find the average length of one pace (B).

(A) $15.5 + 15.3 + 15.7 = 46.5\,m$

$46.5 \div 3 = 15.5\,m$

(B) 15.5 metres is 1550 centimetres.

$1550 \div 20 = 77.5\,cm$

SUMMARY

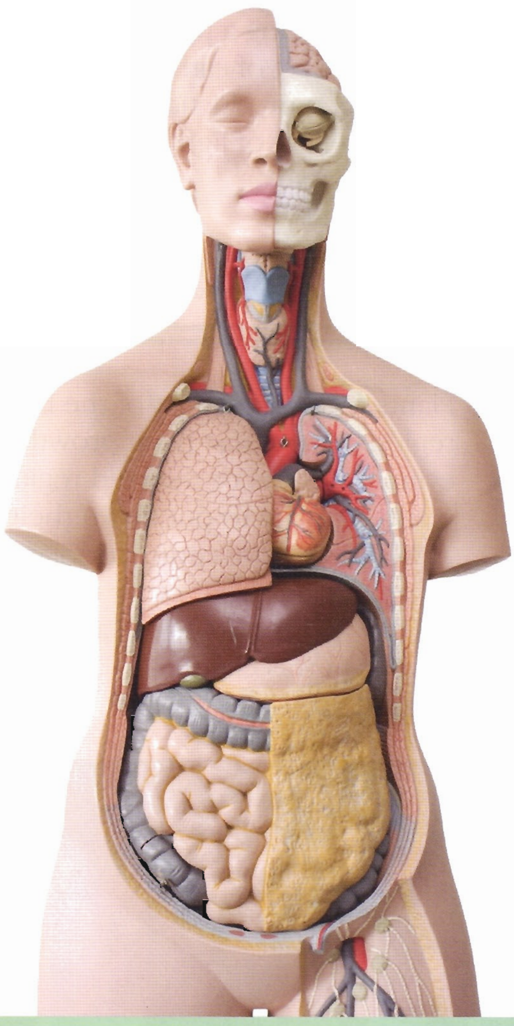
- Science is both an investigative activity and a huge resource of knowledge divided into biology, chemistry and physics (*see page 1*).
- Scientific knowledge is built up by scientific enquiry which has four stages: Considering ideas and evidence, Planning, Obtaining and presenting evidence and Considering evidence and approach (*see pages 3–4*).
- Creative thinking is used in the devising of investigations (*see page 5*).
- In some investigations simple calculations are made (*see page 7*).

End of chapter questions

1 Does the length of your pace change when you change from walking to jogging? Plan an investigation to find out.

2 Plan an investigation to find out if other people have a change in the length of their pace when they change from walking to jogging.

BIOLOGY



1 How plants grow

- A test for starch
- Testing a leaf for starch
- Destarching a plant
- The effect of carbon dioxide on starch production
- Oxygen production in plants
- The effect of light on starch production
- Biomass
- Minerals
- The transport of water through a plant
- How water moves through a leaf

Plants grow over most of the land on the planet. The regions of greatest plant growth are the rainforests but even in deserts or the cold regions around the North Pole plants manage to put down their roots and grow.

We know from caring for plants that they need water to survive but what other things do they need and how do they get them? These are the questions we shall try to answer in this chapter.

Figure 1.1 A rainforest

Figure 1.2 The African desert

Figure 1.3 Willows growing in the tundra

The willow tree experiment

Figure A Watering a willow tree

In the 17th century Joannes Baptista van Helmont (1580–1644), a Belgian scientist, performed an experiment on a willow tree. He was interested in what made it grow. At that time scientists believed that everything was made from four 'elements': air, water, fire and earth. Van Helmont believed that water was the most basic 'element' in the universe and that everything was made from it. He set up his experiment by weighing a willow sapling and the soil it was to grow in. Then he planted the sapling in the soil and provided it with nothing but water for the next 5 years. At the end of his experiment he found that the tree had increased in mass by 73 kilograms but the soil had decreased in mass by only about 60 grams. He concluded that the increase in mass was due to the water the plant had received. If we were to summarise his conclusion, it could look like this:

water → mass of plant

1 How fair was van Helmont's experiment? Explain your answer.
2 Did the result of the experiment support van Helmont's beliefs? Explain your answer.
3 Helmont provided data about the mass of the tree and the mass of the soil. What other data could he have recorded?

4 If you were to repeat van Helmont's experiment, how would you improve it and what table would you construct for recording your results?

A test for starch

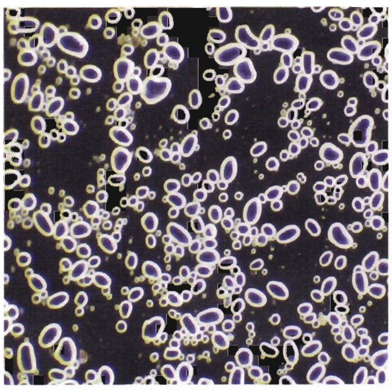


Figure 1.4 Starch grains on a dark background, viewed using a microscope

Many animals, including ourselves, eat plants. The plants contain food and make it as they grow. To find out more about this food-making process it seems reasonable to look for a food that the plant makes. Taking this idea further, a part of a plant that is used for food could be closely examined to see if a food substance can be identified.

The potato, for example, is a tuber produced by the potato plant and is eaten by people in many parts of the world. A search for a food substance in it can begin by cutting a small, very thin slice of a potato and examining it under the microscope. When this is done, the **cells** are found to contain colourless grains of starch which are quite difficult to see. They can be made more visible by adding a dilute solution of iodine to the slice. This turns the starch blue-black.

Testing a leaf for starch

Having discovered a way to identify starch in a part of a plant the investigation can be extended to look for starch in leaves.

Iodine does not produce a colour change when it is placed on a leaf because the **cell walls** will not allow the iodine into the cells and the green pigment masks any colour change. However, a leaf can be tested for starch if it is first treated with boiling water and ethanol. The boiling water makes it easier for liquids to leave and enter the plant cells. The ethanol removes the green pigment, **chlorophyll**, from the leaf and makes the leaf crisp.

If the leaves of a geranium that has been growing on a windowsill or in a greenhouse are tested, they will be found to contain starch.

1 What was the purpose of putting the leaf:
a) in boiling water
b) in ethanol?

Plants and the air

Stephen Hales (1677–1761), an English scientist, discovered that 'a portion of air' helped a plant to survive, and Jan Ingenhousz (1730–1799), a Dutch scientist, showed that green plants take up carbon dioxide from the air when they are put in the light. By this time it was also known that water contains only the elements hydrogen and oxygen while carbohydrates contain carbon, hydrogen and oxygen. All this information led to a review of van Helmont's idea that only water was needed to produce carbohydrates. The review began by considering what else was around the plant apart from water. It was known from van Helmont's work that the soil contributed only a very small amount to the increased mass of the plant. The only other material coming into contact with the plant was the air. Ingenhousz's work suggested that the carbon dioxide in the air was important. You can test this idea in the laboratory today.

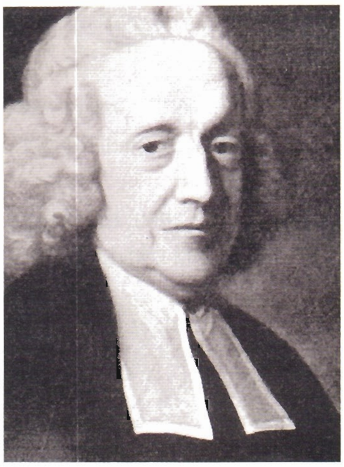


Figure B Stephen Hales

5 Did Hales perform his experiments at the same time as van Helmont (see page 11). Explain your answer.

6 How had the idea of elements changed from the days of van Helmont to the time of Hales and Ingenhousz?

7 Why did a review of van Helmont's work lead to the idea that air could be important in the making of food?

8 How did Ingenhousz's discovery suggest that carbon dioxide might be important in making food?

9 Which two activities in the 'considering evidence and approach' stage in scientific enquiry (see page 4) were being used in reviewing van Helmont's work?

Figure C Jan Ingenhousz

Destarching a plant

If you want to see whether starch has been made, you have to start with a plant that does not contain starch. If a plant that has leaves containing starch is left in darkness for 2 or 3 days, and is then tested again, it will be found that the leaves are starch-free. The plant is described as a destarched plant. It can be used to test for the effect of carbon dioxide.

Investigating the effect of carbon dioxide on starch production

Soda lime is a substance that absorbs carbon dioxide and takes it out of the air. Sodium hydrogencarbonate solution is a liquid that releases carbon dioxide into the air.

Two destarched plants were set up under transparent plastic bags that were sealed with elastic bands. Before covering the plants with the bags, a small dish of soda lime was added to one plant and a small dish of sodium hydrogencarbonate solution was added to the other (see Figure 1.5). Both plants were left in daylight for a few hours before a leaf from each of them was tested for starch.

2 What does soda lime do to the air inside the plastic bag?

3 What does sodium hydrogencarbonate do to the air inside the plastic bag?

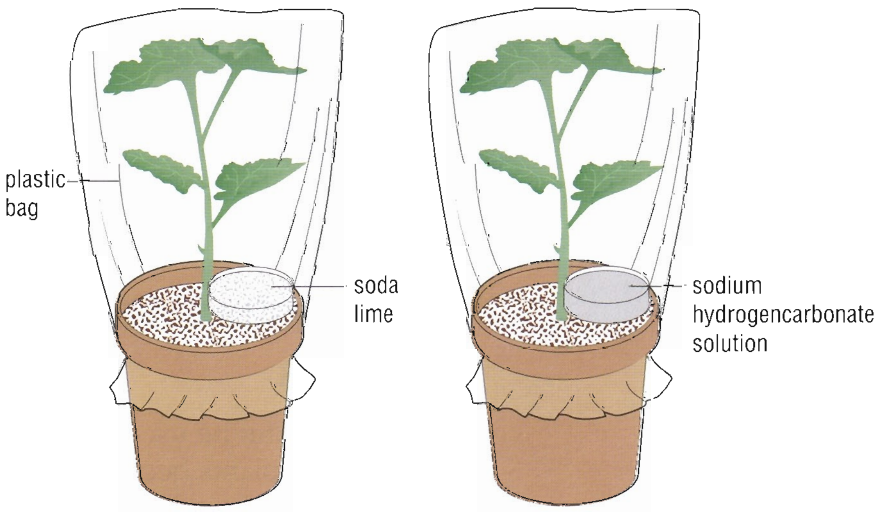


Figure 1.5 Apparatus for investigating the effect of carbon dioxide on starch production by plants

The leaf from the plant with the dish of soda lime did not contain starch but the leaf from the plant with the dish of sodium hydrogencarbonate did contain starch. This suggests that carbon dioxide is needed for starch production.

Plants and oxygen

Joseph Priestley (1733–1804) studied how things burn. At that time scientists used the phlogiston theory to explain how things burnt. They believed that when materials such as wood burnt they lost a substance called phlogiston. When a candle burnt in a closed volume of air, such as the air in a bell jar, they believed that the candle eventually went out because the air had become filled with phlogiston. It had become phlogisticated.

When Priestley put a plant in the air in which a candle had burnt, he found that later on a candle would burn in it again. He reasoned that the plant had taken the phlogiston out of the air and had made dephlogisticated air. Later Ingenhousz re-examined Priestley's results and performed some more investigations. He showed that plants produced oxygen and that the phlogiston theory was wrong.

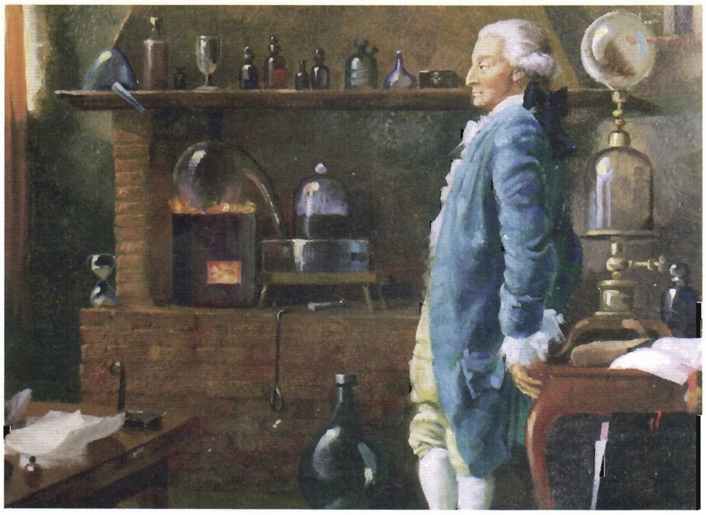


Figure D Scientific apparatus in an 18th century laboratory

10 Which of the scientists van Helmont, Hales and Ingenhousz were alive at the same time as Priestley? Look back at the other Scientific Enquiry boxes on pages 11 and 12 to find out.

11 Is it possible to make investigations using the wrong theory? Explain your answer.

12 How was Priestley's conclusion to his investigations eventually proved wrong?

Investigating oxygen production in plants

Water plants can be used to investigate the gases produced by plants because the gases escape from their surface in bubbles that can be easily seen and collected.

Two samples of Canadian pondweed were set up as shown in Figure 1.6. One was put in a sunny place and the other was kept in the dark. After about a week the amount of gas collected in each test tube was examined. The plants in the dark had not produced any gas. The plants in the light had produced gas and, when it was tested with a glowing splint, the splint re-lighted, showing that the gas contained more oxygen than normal air.

For discussion

The rainforests have been described as the world's lungs. What do you think this means?

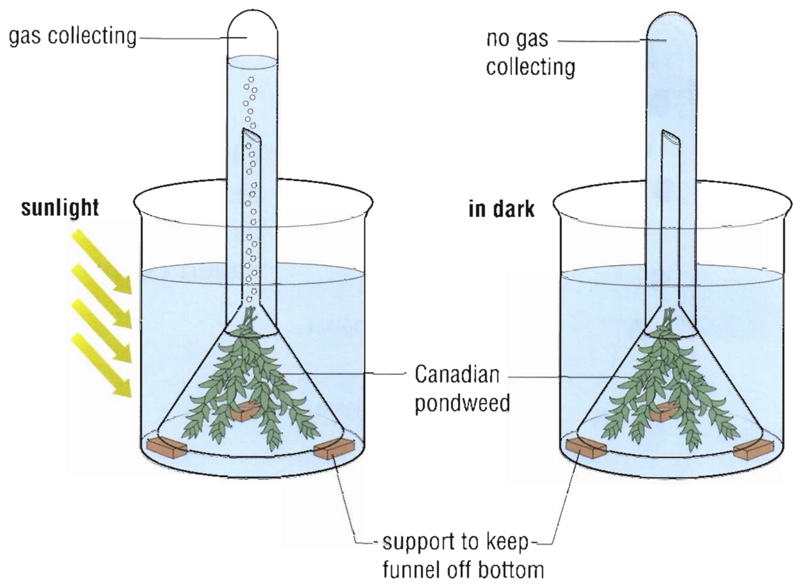


Figure 1.6 Apparatus for investigating oxygen production by plants

Plants and light

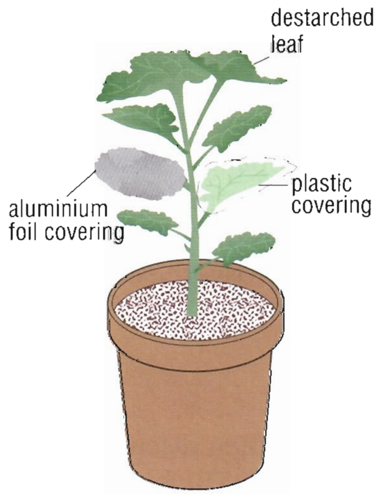


Figure 1.7 Apparatus for investigating the effect of light on plants

Having discovered that plants take in water and carbon dioxide, produce starch and give out oxygen it seems reasonable to look for a source of energy which can help them carry out these activities. As light is a form of energy and present during the day it would also seem reasonable to perform tests to see if light can affect the production of starch.

Two leaves of a destarched plant were set up as shown in Figure 1.7 and left for over 4 hours in daylight. After that time they were removed and tested for the presence of starch.

The leaf kept in the transparent plastic sheet contained starch. The leaf kept in the aluminium sheet did not contain any starch. This suggests that light is needed for starch to form in a leaf.

Energy transfer in photosynthesis

The process in plants of using light and forming starch is called **photosynthesis**. The transfer of energy can be shown by an energy transfer diagram. At the centre of the diagram is the energy converter or transducer. In plants this is a green substance called chlorophyll. In photosynthesis the plant takes in energy in the form of light and some of the energy is transferred into chemical energy in the form of starch.

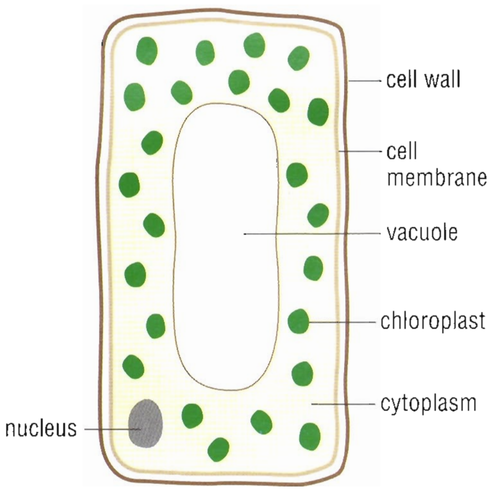


Figure 1.8 A palisade cell

The energy transfer diagram for photosynthesis is:

light energy → chlorophyll → stored chemical energy

Chlorophyll is the substance which makes the leaves appear green. It is found in leaf cells such as those called palisade cells in structures called **chloroplasts**.

Reviewing the work on plant and food production

When a series of investigations has been made, scientists review all the work to see how it fits together to build up an explanation of what they have found out. As they review their work they can also acknowledge the work of other scientists before them whose work led to the investigations and discoveries being made today. In this series of investigations the work of van Helmont, Hales, Ingenhousz and Priestley has been acknowledged. A review of the investigations shows that plants use water, carbon dioxide and energy in sunlight to make food and during this process they also produce oxygen. This process of making food using light is called photosynthesis.

Biomass

Scientists often use the word **biomass** when discussing the amount of matter or mass in a living thing. The biomass can be found by weighing the living thing. For example, in van Helmont's willow tree experiment he measured the biomass when he weighed the plant at the beginning and end of the experiment. The experiment showed that the biomass of the plant had increased. The investigations which followed van Helmont's have shown that photosynthesis is responsible for making biomass as well as oxygen.

In the previous paragraph the term biomass was used to describe the mass of a living thing when it is alive. This is called the wet biomass. Usually scientists want to know the biomass of the organism after the water has been removed as this is a more accurate measurement of the actual matter which formed the living part of the

organism. This means that the living thing has to be killed and dried out. It is then weighed to find its dry biomass.

Biomass can be used to monitor the environment. The biomass of a species of plant or animal in a habitat can be found by weighing some individuals and estimating the number in the habitat. This can then be checked from time to time to see if there is a change in the biomass of the species which might indicate environmental change.

The word biomass is also used in the context of renewable energy sources. In this context it means plants grown to be used as fuel such as wood in Africa and India.

For discussion

Why is the dry biomass considered to be more accurate than the wet biomass?

Is obtaining the dry biomass of a species in a habitat justifiable?

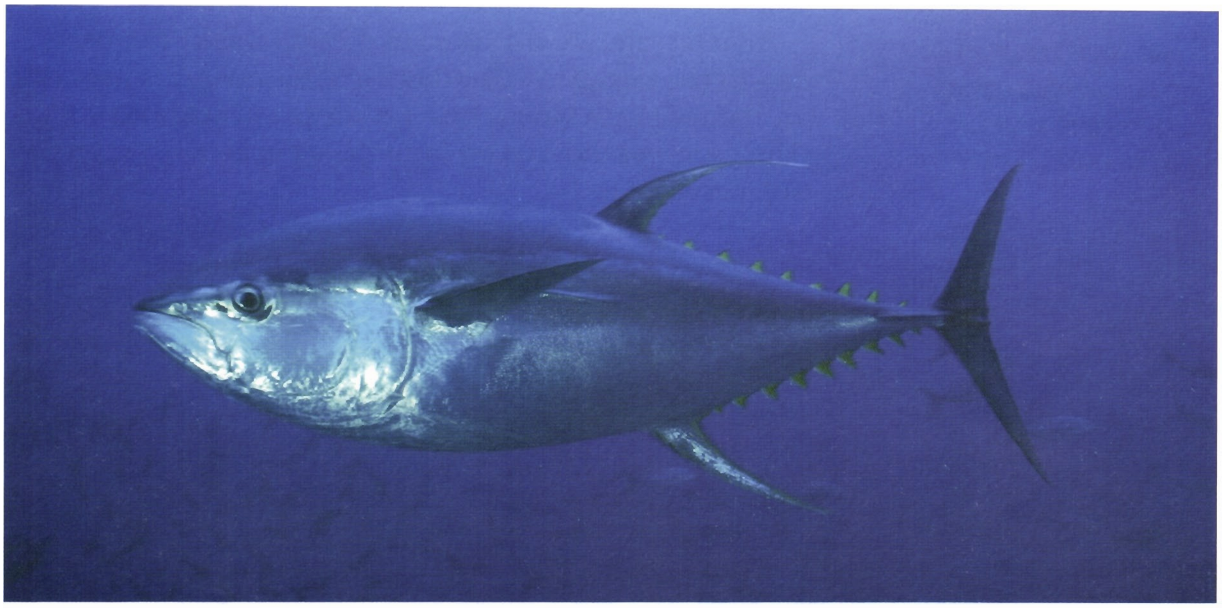


Figure 1.9 Changes in the biomass of fish like the yellow fin tuna are studied to see how fishing affects the population sizes of fish in the oceans.

Minerals

Over four hundred years ago when van Helmont performed his experiment, he found that the mass of the soil decreased by 60 grams in five years. He did not follow up this result but over the centuries scientists have studied the soil more closely and discovered that it contains substances called **mineral salts** that plants need in order to survive. Two examples of mineral salts are potassium phosphate and calcium nitrate but there are many more. The minerals dissolve in the water in the soil and are taken into the plant by the roots. Then they are moved through the plant to where they are needed.

The transport of water through a plant

Most plant roots have projections called root hairs. The tips of the root hairs grow out into the spaces between the soil particles. There may be up to 500 root hairs in a square centimetre of root surface. They greatly increase the surface area of the root so that large quantities of water can pass through them into the plant. The water in the soil is drawn into the plant to replace the water that is lost through evaporation from the leaves. The plant does not have to use energy to take the water in.

Mineral salts are dissolved in the soil water. The plant has to use energy to take them in. This energy is provided by the root cells when they use oxygen in **respiration**. The roots get the oxygen from the air spaces between the soil particles.

4 If a plant is over-watered, all the spaces between the soil particles become filled with water. How does this waterlogged soil affect:
a) the plant's roots
b) the plant's growth?

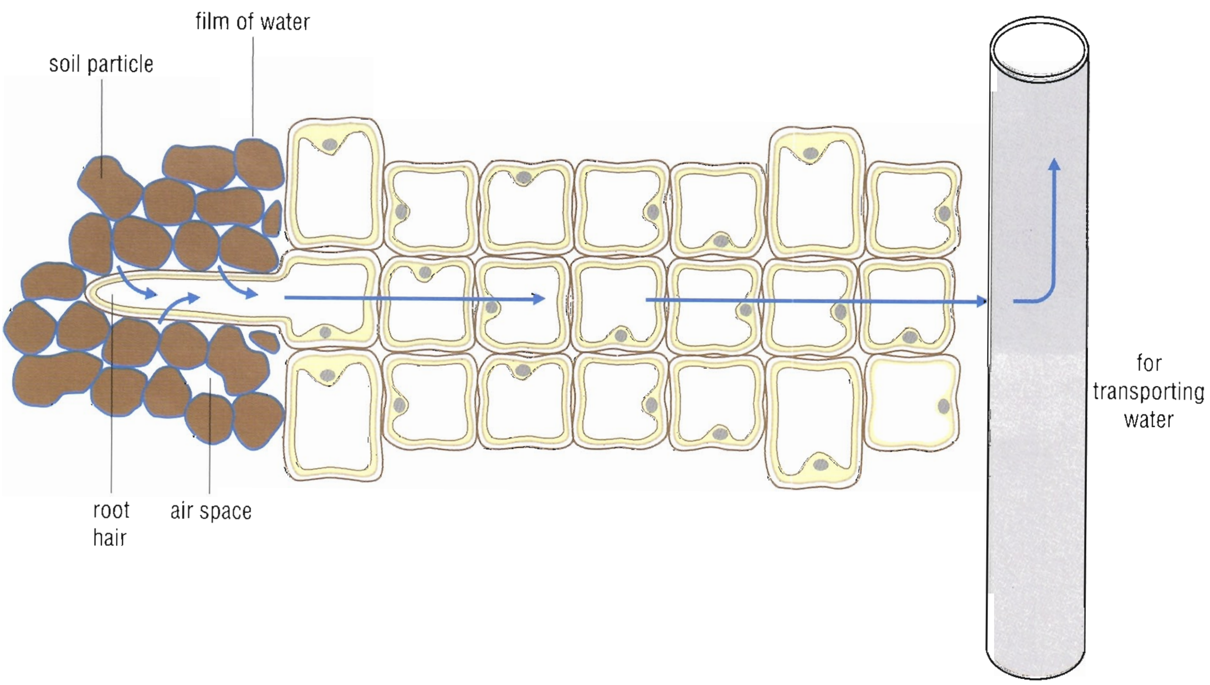


Figure 1.10 Schematic drawing of the movement of water and mineral salts in the root of a plant

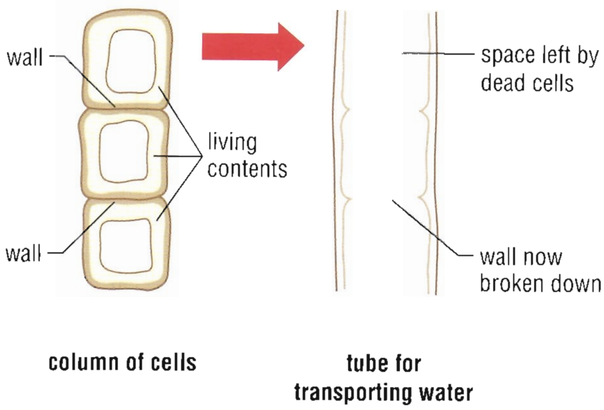


Figure 1.11 How a tube for transporting water is made

Tubes for transporting water

There are cells in the plant which form tubes to transport water. The cells form columns in the plant and when they die the walls between them break down to form tubes (see Figure 1.11).

Each water-conducting tube is called a **xylem** (pronounced *zylem*) vessel. A group of vessels form xylem tissue, which makes up part of structures called vascular bundles. These run through the plant from the root to the leaf where they form leaf veins. If you eat celery, you have already met vascular bundles. They form the fibres which sometimes stick between your teeth!

The root and water

The root pushes water up a plant a little way. If a low branch on a tree is removed in spring, water may ooze from the cut because of the root pushing the water upwards. The power of the root to push up water can also be seen if the stem of a pot plant is cut near the soil surface and a glass tube is attached to it. When a small amount of water is added to the tube and it is left for a while, the water level will be seen to rise a little.

However, the power of the root to push water up the stem is not great. The water reaches all parts of the stem due to the action of the leaves.

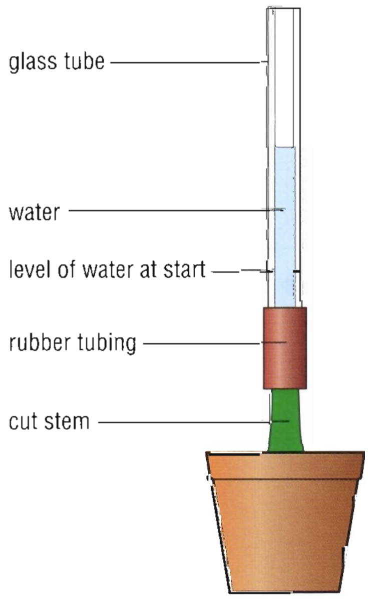


Figure 1.12 Apparatus to show that a root pushes water upwards

The cell structure of a leaf

If you look at a cross section of a leaf under the microscope (see Figure 1.13), you will see that the cells form a number of tissues. The upper and lower surfaces are made from a layer one cell thick. This is called the **epidermis**. On the outer surface of the epidermal cells is a layer of wax which prevents water passing in or out of the leaf. On the lower side of the leaf, holes called **stomata** may be seen (see Figure 1.14).

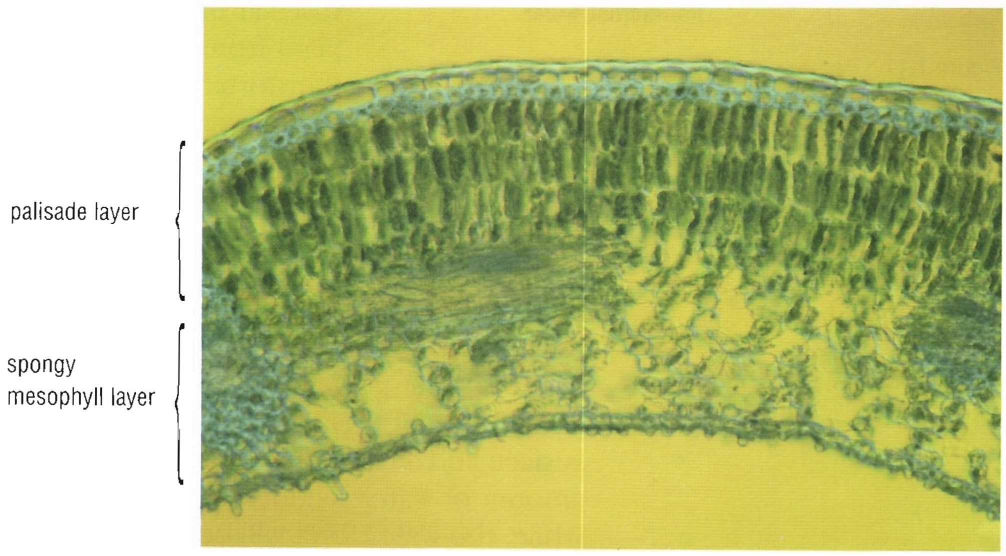


Figure 1.13 Cross section of a leaf. The cells in the palisade layer are tightly packed while the cells in the spongy mesophyll have some air spaces between them.

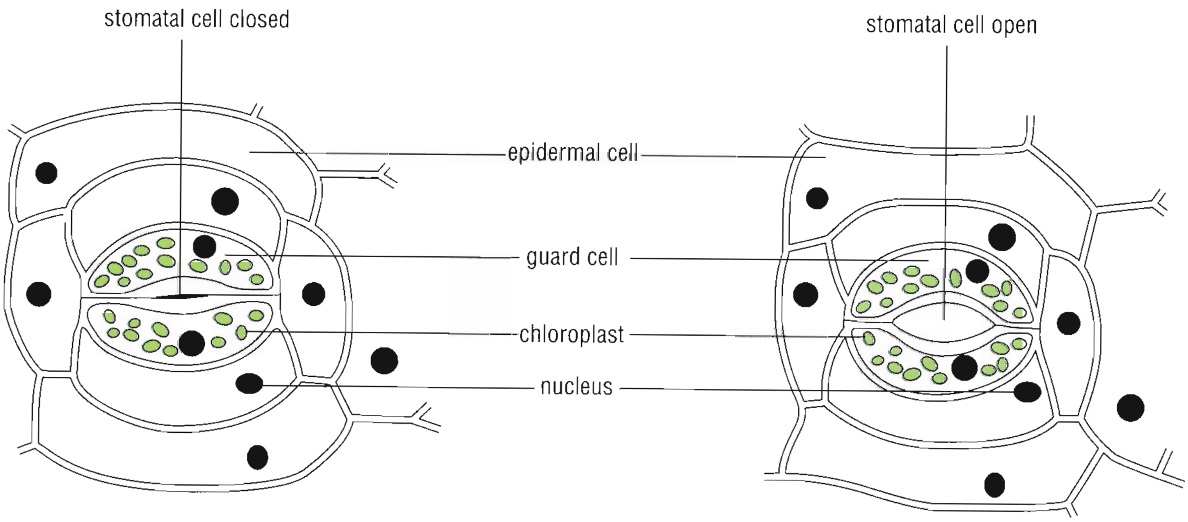


Figure 1.14 Stomata

Between the upper and lower epidermis are two more tissues. The upper tissue is called **palisade tissue**; its cells are mainly involved with making food. Below the palisade tissue is the **spongy mesophyll**. The cells in this tissue also make food but in addition they provide a surface for the evaporation of water.

The **veins** in a leaf appear as circles or ovals in cross section. They contain **vascular bundles** made up of xylem tissue, which carries water to the leaf, and **phloem tissue**, which carries food away.

5 a) Name the tissues labelled A, B and C in the section of a leaf shown in Figure 1.15.
b) What is X?
6 Describe the passage of a water molecule from the soil, up the transpiration stream, to mixing with other air particles as water vapour.
7 a) How does temperature affect the evaporation of water in a dish?
b) How do you think temperature will affect transpiration in a plant?
8 a) If washing is pegged outside to dry, will it dry more quickly in still or windy conditions?
b) How do you think windy conditions will affect the rate of transpiration?
9 Humid air contains a large amount of water vapour. This makes it more difficult for water particles to evaporate from a dish of water. Will humid conditions speed up or slow down the rate of transpiration?

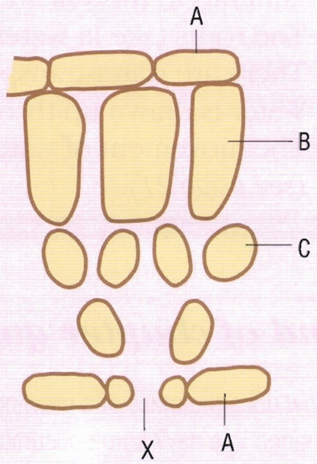


Figure 1.15

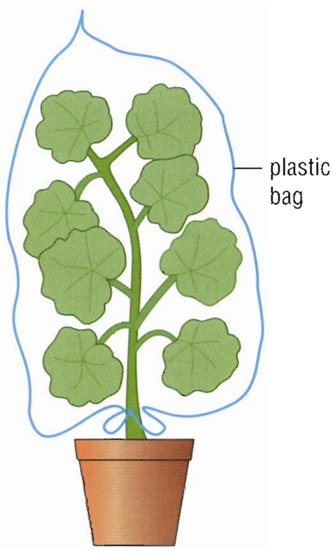


Figure 1.16 Apparatus to show transpiration

How water moves through a leaf

When water evaporates from cells in the spongy mesophyll layer, water vapour forms. If there is less water vapour outside the leaf than inside it, the water vapour will diffuse out through the stomata. This makes the spongy mesophyll cells short of water so they take more from the xylem tissue in the veins. The water lost in the veins is replaced by water passing up the xylem tissue in the stem and root. The process by which plants lose water from their leaves is called transpiration and the movement of water from the roots through the stem to the leaves is called the transpiration stream.

The release of water by transpiration can be shown by placing a clear plastic bag around the shoot of a pot plant (see Figure 1.16). The liquid inside the bag can be tested with cobalt chloride paper. If the paper turns pink the liquid is water.

10 Look at Figure 1.16. How could you perform an experiment to show that the amount of water collected was due to the leaves and not the stem?

SUMMARY

- Starch can be detected with dilute iodine solution (*see page 11*).
- A leaf must be decolourised and softened before it is tested for starch (*see page 12*).
- A plant must be destarched before using it in a photosynthesis investigation (*see page 13*).
- Carbon dioxide is used in the production of starch (*see page 13*).
- Plants produce oxygen when light shines on the leaves (*see page 14*).
- Plants produce starch in their leaves when light shines on them (*see page 15*).
- Biomass is the amount of matter in a living thing (*see page 16*).
- Minerals in the soil are needed by plants to survive (*see page 17*).
- The roots take in water (*see page 18*).
- There are water-transporting tubes inside the plant called xylem vessels (*see page 19*).
- Water is drawn up through the plant by the leaves (*see page 21*).
- The movement of water through a plant is called the transpiration stream (*see page 21*).

End of chapter question

How does the mass of a growing cucumber change in a day? Large cucumbers appear to grow quickly. In this experiment a cucumber plant was placed close to a top-pan balance and one of its growing cucumbers was placed on the pan. The mass of the cucumber was measured every hour between 9a.m. and 4p.m. The mass is displayed in the graph in Figure 1.17.

a) What was the gain in mass over the 7-hour period?

b) Construct a table to display the increase in mass in each of the 7 hours.

c) When was the period of:

i) greatest growth

ii) least growth?

d) If the cucumber plant had some of its leaves removed before the experiment, how would you expect the graph of its growth to compare with the graph in this experiment? Explain your answer.

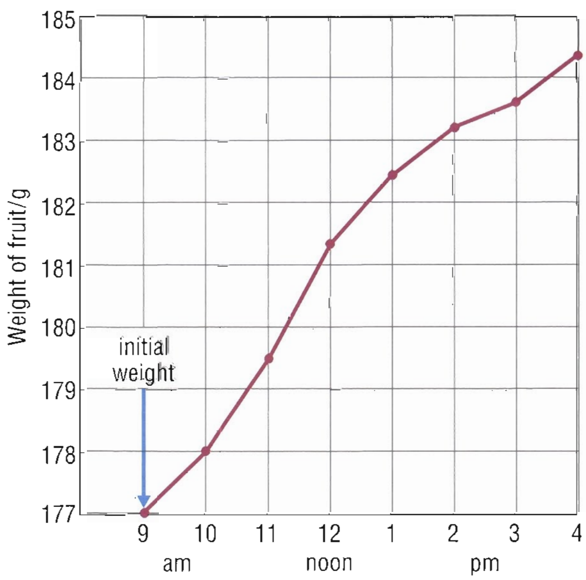


Figure 1.17

2 A healthy diet

- Nutrients needed by the body
- How the body uses different nutrients
- The nutrient content of different foods
- A balanced diet
- Malnutrition
- A plan for a healthy diet

Figure 2.1 A school canteen

1. Write a description of your daily eating pattern.
2. Compare your pattern with the two on this page. Which one does your pattern resemble?
3. From what you already know, try to explain which diet is healthier.

What kind of diet do you have? Here are two examples.

Diet 1

- No breakfast
- Eat sweets on the way to school
- Eat a chocolate bar and have a fizzy drink at morning break
- Have fried food such as potato chips with lunch
- Eat some more sweets in the afternoon
- Avoid green vegetables in evening meal
- Have a snack of crisps, sweets and fizzy drink during the evening

Diet 2

- Have breakfast of cereal and milk, toast and fruit juice
- Eat an apple at morning break
- Have a range of foods for lunch during the week including different vegetables, pasta and rice
- Eat an orange in the afternoon
- Eat an evening meal with green vegetables
- Have a milky drink at bedtime

Nutrients

> **For discussion**
>
> **How healthy is your eating pattern? What changes would make it healthier? Do other people agree?**

A chemical that is needed by the body to keep it in good health is called a **nutrient**. The human body needs a large number of different nutrients to keep it healthy. They can be divided up into the following nutrient groups:

- carbohydrates
- fats
- proteins
- vitamins
- minerals.

In addition to these nutrients the body also needs water. It accounts for 70% of the body's weight and provides support for the cells. It carries dissolved materials around the body and helps in controlling body temperature.

Fibre is also needed by the body.

Carbohydrates

Carbohydrates are made from the elements carbon, hydrogen and oxygen. The atoms of these elements are linked together to form molecules of sugar. There are different types of sugar molecule but the most commonly occurring is glucose. Glucose molecules link together in long chains to make larger molecules such as starch. Glucose and starch are two of the most widely known carbohydrates but there are others, such as cellulose.

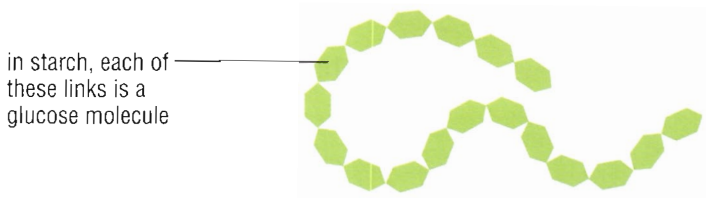


Figure 2.2 A carbohydrate molecule

Fats

Fats are made of large numbers of carbon and hydrogen atoms linked into long chains together with a few oxygen atoms. There are two kinds of fats, the solid fats produced by animals, such as lard, and the liquid fat or oil produced by plants, such as sunflower oil.

4 What elements are found in carbohydrates, fats and proteins?

5 Which two words are used to describe the structure of carbohydrate, fat and protein molecules?

6 A science teacher held up a necklace of beads to her class and said it was a model of a protein molecule. What did each bead represent?

Proteins

Proteins are made from atoms of carbon, hydrogen, oxygen and nitrogen. Some proteins also contain sulfur. The atoms of these elements join together to make molecules of amino acids. Amino acids link together into long chains to form protein molecules.

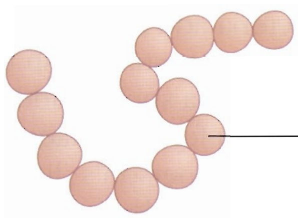
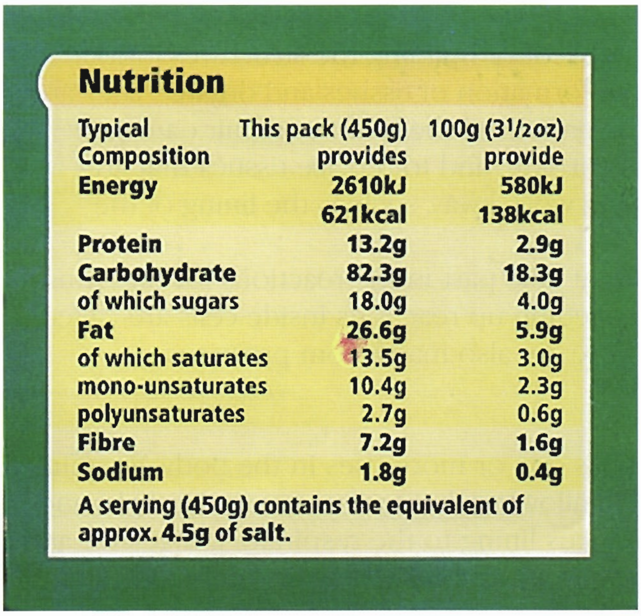


Figure 2.3 A protein molecule

Vitamins

Unlike carbohydrates, fats and proteins, which are needed by the body in large amounts, **vitamins** are needed in only small amounts. When vitamins were first discovered, they were named after letters of the alphabet. Later, when the chemical structure of their molecules had been worked out, they were given chemical names.



Nutrition

Typical Composition	This pack (450g) provides	100g (3½oz) provide
Energy	2610kJ	580kJ
	621kcal	138kcal
Protein	13.2g	2.9g
Carbohydrate	82.3g	18.3g
of which sugars	18.0g	4.0g
Fat	26.6g	5.9g
of which saturates	13.5g	3.0g
mono-unsaturates	10.4g	2.3g
polyunsaturates	2.7g	0.6g
Fibre	7.2g	1.6g
Sodium	1.8g	0.4g

A serving (450g) contains the equivalent of approx. 4.5g of salt.

Figure 2.4 The nutrients in a food product are displayed on the side of the packet.

Minerals

The body needs twenty different **minerals** to keep healthy. Some minerals, such as calcium, are needed in large amounts but others, such as zinc, are needed in only tiny amounts and are known as trace elements.

How the body uses nutrients

Carbohydrates

Carbohydrates contain a large amount of energy that can be released quickly inside the body. They are used as fuel to provide the energy for keeping the body alive.

Fibre

Cellulose is a carbohydrate which makes up the walls of plant cells. The cellulose in food is known as dietary fibre. It is found in foods such as wholemeal bread, fruit and vegetables. We cannot digest fibre but it helps to move food along the intestines. As the fibre moves through the large intestine, bacteria feed on it and together the fibre and bacteria add bulk to the food. This helps the muscles of the large intestine push the food along. Fibre also takes up water like a sponge and this makes the undigested foods which form the faeces soft and easy to release from the body. If a person's diet lacks fibre, they may suffer from bowel problems such as constipation.

Fats

Fats are needed for the formation of **cell membranes**. They also contain even larger amounts of energy than carbohydrates. The body cannot release the energy in fats as quickly as the energy in carbohydrates so fats are used to store energy. In mammals the fat forms a layer under the skin. This acts as a heat insulator and helps to keep the mammal warm in cool conditions. Many mammals increase their body fat in the autumn so that they can draw on the stored energy if little food can be found in the winter. Some plants store oil in their seeds.

Proteins

Proteins are needed for building the structures inside cells and in the formation of tissues and organs. They are needed for the growth of the body, to repair damaged parts, such as cut skin, and to replace tissues that are constantly being worn away, such as the lining of the mouth.

Chemicals that take part in the reactions for digesting food and in speeding up reactions inside cells are called **enzymes**. These are also made from proteins.

Vitamins

Each vitamin has one or more uses in the body. Vitamin A is involved in allowing the eyes to see in dim light and in making a mucus lining to the respiratory, digestive and excretory systems which protects against infection from microorganisms.

There are several B vitamins of which vitamin B_1 (thiamin) is an example (see page 27).

Finding the cause of beriberi

Christiaan Eijkman (1858–1930) was a Dutch doctor who worked at a medical school in the East Indies in the late 19th century. He investigated the disease called beriberi. In this disease the nerves fail to work properly and the action of the muscles becomes weak. All movements, especially walking, become difficult and, as the disease progresses, the heart may stop. At this time other scientists had recently shown that microorganisms cause a number of diseases. It seemed reasonable to think that beriberi was also caused by a microorganism of some kind. Eijkman set up some investigations to find out. He was not having any success. Then one day a flock of chickens that were kept at the medical school began to show the symptoms of beriberi.

Eijkman tested them for signs of the microorganisms that he believed were causing the disease. Again he had no success in linking the disease to the microorganisms but, while he was studying the chickens, they recovered from the disease.

Eijkman began to search for a reason why they had developed the disease and also why they had recovered so quickly. He discovered that the chickens were usually fed on chicken feed (a specially prepared mixture of foods that keeps them healthy). A cook who had been working at the medical school had stopped using the chicken feed and had fed the chickens on rice that had been prepared for the patients. This cook had left and a new cook had been employed who would not let the rice be fed to the chickens. The birds were once again fed on chicken feed. When Eijkman fed the chickens on rice again they developed beriberi. When he fed them on chicken feed they recovered from the disease straight away.

The rice fed to the chickens and the patients was polished rice. This has had its outer skin removed and appears white. Later work by scientists showed that the skin of rice contains vitamin B_1 or thiamin. This vitamin is needed to keep nerves healthy and prevent beriberi.

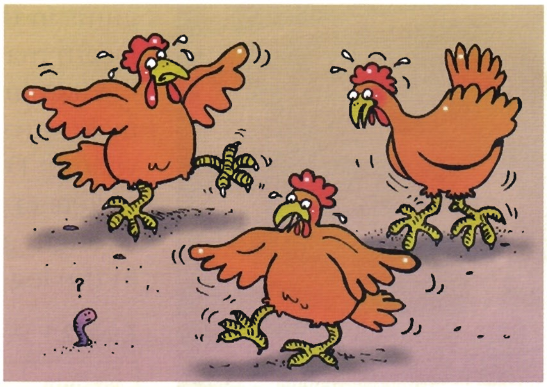


Figure A A flock of hens with beriberi

For discussion

Eijkman performed his experiments on animals. Question 7 asked you to plan an investigation to check his work.

Your plan may have featured studying animals. A great deal of information that benefits humans has been gathered by studying animals in experiments. Are there any guidelines that you would want scientists to follow in experiments involving animals?

1 What are the symptoms of beriberi?
2 How serious is the disease?
3 Why did Eijkman begin by looking for microorganisms as a cause of beriberi?
4 In what way did chance play a part in the discovery of the cause of beriberi? Explain your answer.
5 How did Eijkman's work alter the way scientists thought diseases developed?
6 What is the danger in having a diet which consists mainly of polished rice? Explain your answer.

7 Write down a plan for an investigation to check Eijkman's work on chickens and beriberi. How would you make sure it was fair and that the results were reliable?

Figure 2.5 This child is suffering from rickets. It can be prevented by adding vitamin D to the diet.

A lack of vitamin C causes the deficiency disease called scurvy. As the disease develops, bleeding occurs at the gums in the mouth, under the skin and into the joints. Death may occur due to massive bleeding in the body.

Vitamin D helps the body take up calcium from food to make strong bones and teeth. Children who have a lack of vitamin D in the diet develop the deficiency disease called rickets in which the bones do not develop to their full strength and may therefore bend. This is seen particularly in the leg bones as shown in the X-ray in Figure 2.5.

Table 2.1 Vitamins and their uses

Vitamin	Effect on body	Good sources
A	increased resistance to disease helps eyes to see in the dark	milk, liver, cod-liver oil
B_1	prevents digestive disorders prevents the disease beriberi	bread, milk, brown rice, soyabean, potato
C	prevents the disease scurvy in which gums bleed and the circulatory system is damaged	blackcurrant, orange, lemon, papaya, guava
D	prevents the disease rickets in which bones become soft and leg bones of children may bend	egg yolk, butter, cod-liver oil, pilchard, herring, sunlight

Minerals

Each mineral may have more than one use. For example, calcium is needed to make strong bones and teeth. It is also needed to make muscles work and for blood to clot. A lack of calcium in the diet can lead to weak bones and high blood pressure. The mineral iron is used to make the red blood pigment called haemoglobin.

Water

About 70% of the human body is water. The body can survive for only a few days without a drink of water.

Every chemical reaction in the body takes place in water. The blood is made mainly from water. It is the liquid that transports all the other blood components around the body.

Water is used to cool down the body by the evaporation of sweat from the skin.

7 A meal contains carbohydrate, fat, protein, vitamin D, calcium and iron. What happens to each of these substances in the body?
8 Which carbohydrate cannot be digested by humans and how does it help the digestive system?
9 In a patient suffering from rickets, why do the leg bones bend more than the arm bones?
10 A seal (see Figure 2.6) is a mammal. How can it survive in the cold polar seas when a human would die in a few minutes?

Figure 2.6 Seals on the ice

The amounts of nutrients in food

The amounts of nutrients in foods have been worked out by experiment and calculation. The amounts are usually expressed for a sample of food weighing 100 g. Table 2.2 on page 30 shows the nutrients in a small range of common foods.

11 In Table 2.2 on page 30, which foods contain the most:
 a) protein
 b) fat
 c) carbohydrate
 d) calcium
 e) iron
 f) vitamin C
 g) vitamin D?
12 Which foods would a vegetarian not eat?
13 Which foods would a vegetarian have to eat more of and why?
14 Which food provides all the nutrients?
15 Why might you expect this food to contain so many nutrients?

Keeping a balance

To remain healthy the diet has to be balanced with the body's needs. A balanced diet is one in which all the nutrients are present in the correct amounts to keep the body healthy. You do not need to know the exact amounts of nutrients in each food to work out whether you have a healthy diet. A simple way is to look at a chart showing food divided into groups, with the main nutrients of each group displayed (see Table 2.3). You can then see if you eat at least one portion from each group each day and more portions of the food groups that lack fat. Remember that you also need to include fibre even though it is not digested. It is essential for the efficient movement of food through the large intestine. Fibre is found in cereals, vegetables and pulses, such as peas and beans.

Table 2.2 The nutrients in some common foods

Food (100 g)	Protein (g)	Fat (g)	Carbohydrate (g)	Calcium (mg)	Iron (mg)	Vitamin C (mg)	Vitamin D (µg)
potato	2.1	0	18.0	8	0.7	8–30	0
carrot	0.7	0	5.4	48	0.6	6	0
bread	9.6	3.1	46.7	28	3.0	0	0
spaghetti	9.9	1.0	84.0	23	1.2	0	0
rice	6.2	1.0	86.8	4	0.4	0	0
lentil	23.8	0	53.2	39	7.6	0	0
pea	5.8	0	10.6	15	1.9	25	0
jam	0.5	0	69.2	18	1.2	10	0
peanut	28.1	49.0	8.6	61	2.0	0	0
lamb	15.9	30.2	0	7	1.3	0	0
milk	3.3	3.8	4.8	120	0.1	1	0.05
cheese 1	25.4	35.4	0	810	0.6	0	0.35
cheese 2	15.3	4.0	4.5	80	0.4	0	0.02
butter	0.5	81.0	0	15	0.2	0	1.25
chicken	20.8	6.7	0	11	1.5	0	0
egg	12.3	10.9	0	54	2.1	0	1.50
fish 1	17.4	0.7	0	16	0.3	0	0
fish 2	16.8	18.5	0	33	0.8	0	22.2
apple	0.3	0	12.0	4	0.3	5	0
banana	1.1	0	19.2	7	0.4	10	0
orange	0.8	0	8.5	41	0.3	50	0

Notes for Tables 2.2 and 2.4

Vegetables are raw; the bread is wholemeal bread; cheese 1 is cheddar cheese; cheese 2 is cottage cheese; fish 1 is a white fish such as cod; fish 2 is an oily fish such as herring

Table 2.3 The groups of foods and their nutrients

Vegetables and fruit	Cereals	Pulses	Meat and eggs	Milk products
carbohydrate	carbohydrate	carbohydrate	protein	protein
vitamin A	protein	protein	fat	fat
vitamin C	B vitamins	B vitamins	B vitamins	vitamin A
minerals	minerals	iron	iron	B vitamins
fibre	fibre	fibre		vitamin C
				calcium

16 Table 2.4 shows the amount of energy provided by 100 g of each of the foods shown in Table 2.2.

a) Arrange the nine foods with the highest energy values in order, starting with the highest and ending with the lowest.

b) Look at the nutrient content of these foods in Table 2.2. Arrange the nine foods from part **a)** into groups according to whether you think the energy is stored as fat or as carbohydrate.

c) Do fats and carbohydrates store the same amount of energy (see also page 26)? Explain your answer.

17 Why might people who are trying to lose weight eat cottage cheese instead of cheddar cheese?

18 Mackerel is an oily fish. Describe the nutrients you would expect it to contain.

19 Look again at the eating pattern you prepared for question **1** on page 23. Analyse your diet into the food groups shown in Table 2.3. How well does your diet provide you with all the nutrients you need?

Table 2.4 The energy value of some common foods

Food (100 g)	Energy (kJ)
potato	324
carrot	98
bread	1025
spaghetti	1549
rice	1531
lentil	1256
pea	273
jam	1116
peanut	2428
lamb	1388
milk	274
cheese 1	1708
cheese 2	480
butter	3006
chicken	602
egg	612
fish 1	321
fish 2	970
apple	197
banana	326
orange	150

20 Table 2.5 shows how the energy used by an average male person and an average female person changes from the age of 2 to 25 years.

a) Plot the information given in the table as a single graph.

b) Describe what the graph shows.

21 Explain why there is a difference between the amounts of energy used by a 2-year-old child and an 8-year-old child.

22 Explain why there is a difference between the amounts of energy used by an 18-year-old male and an 18-year-old female.

23 Explain why there is a change in the amount of energy used as a person ages from 18 to 25.

24 What changes would you expect in the amount of energy used by:

a) a 25-year-old person who changed from a job delivering letters and parcels to working with a computer

b) a 25-year-old person who gave up working with computers and took a job on a building site that involved carrying heavy loads

c) a 25-year-old female during pregnancy?

Table 2.5 Average daily energy used by males and females

Age (years)	Daily energy used (kJ)	
	Male	Female
2	5500	5500
5	7000	7000
8	8800	8800
11	10000	9200
14	12500	10500
18	14200	9600
25	12100	8800

Malnutrition

If a diet provides too few nutrients or too many nutrients malnutrition occurs. You can learn more about malnutrition in Chapter 7. Lack of a nutrient in a diet may produce a deficiency disease, such as scurvy or **anaemia**. Scurvy is a deficiency disease caused by a lack of vitamin C and anaemia is a deficiency disease caused by a lack of iron.

If more protein than is needed is eaten, it is broken down in the body. Part of it is converted to a carbohydrate called glycogen, which is stored in the liver, and part of it is converted to a chemical called **urea**, which is excreted in the **urine**. Too much high-energy food such as carbohydrate and fat leads to the body becoming overweight. If the body is extremely overweight it is described as obese.

If too little high-energy food is eaten the body becomes thin because it uses up energy stored as fat. Energy stored in protein in the muscles can also be used up. The condition anorexia nervosa can lead to extreme weight loss and possibly death. It occurs mainly in teenage girls but is occurring increasingly in teenage boys and adult men and women. People suffering from anorexia nervosa eat very little and fear gaining weight. As soon as the condition is diagnosed, they need careful counselling to give them the best chance of making a full recovery.

25 What happens in the body if too much fat, carbohydrate or protein is eaten?

26 Why do people become thin if they do not eat enough high-energy food?

A healthy diet

The body needs a range of nutrients to keep healthy (see pages 24–28) and everyone should eat a balanced diet to provide these nutrients. Regular eating of high-energy snacks, such as sweets, chocolate, crisps, ice cream and chips, between meals unbalances the diet and can lead to the body becoming overweight, damage to the teeth (see pages 36–37) and ill-health. Overweight people have to make more effort than normal to move so they tend to take less exercise. In time this can affect the heart (see page 52).

High-energy snacks should be kept to a minimum so that the main meals of the day, which provide most of the essential nutrients, may be eaten. There are alternatives to high-energy snacks. These are fruits and raw vegetables, such as celery, tomatoes and carrots. In addition to being lower in energy they also provide more vitamins and minerals. You can think about the amounts of food you eat in the following way.

You can eat large amounts of potatoes, bread, rice and pasta. They provide you with carbohydrates, which supply the body with energy. You should eat a smaller amount of fruit and vegetables (but still five portions a day) to provide you with vitamins, minerals and fibre. You should eat a smaller amount still of foods such as meat and fish, to provide you with the protein you need for growth and repair of the body. In a vegetarian diet protein is mainly provided by pulses such as beans, lentils and peas. Finally you should eat even smaller amounts of food rich in fat such as chocolate, nuts, fatty meat and cheese. Fat provides materials for making cell membranes. It also creates an insulating layer beneath the skin that helps to retain body heat. This layer acts as an energy store for the body but there can be dangers to health if it becomes too thick.

An easy way to think about all this information is to think of a pyramid of food (see Figure 2.7).

27 Make a pyramid of food representing your diet. Describe how it compares with the pyramid in Figure 2.7. If it does not match the pyramid in the diagram, how can you change your diet to make it healthier? **Note**: this pyramid of food is simply to make you think about eating healthily. It is not related to food pyramids of organisms that may be made in habitat studies.

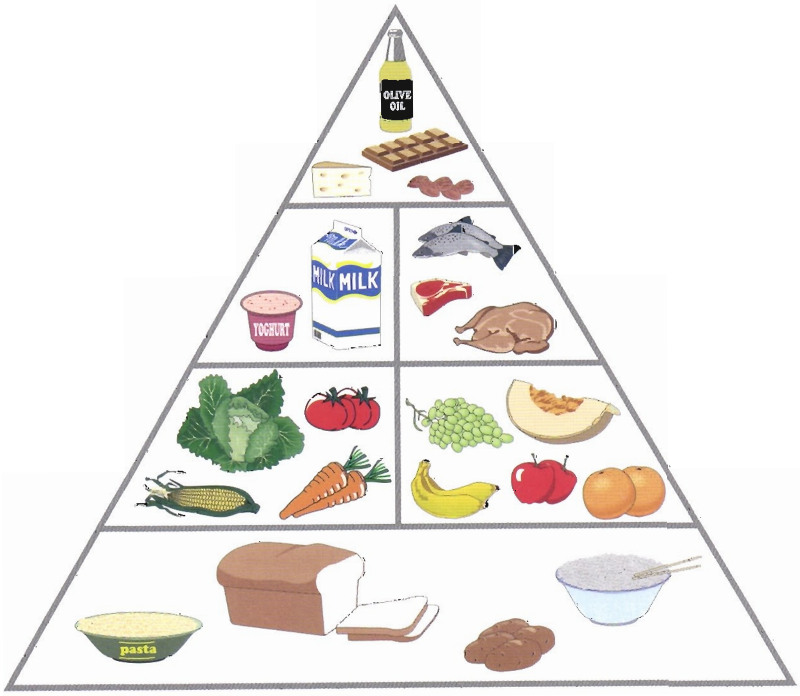


Figure 2.7 A pyramid of food

The pyramid reminds you that you should eat large amounts of foods at the bottom of the pyramid but only small amounts of those at the top.

SUMMARY

- A chemical that is needed by the body to keep it healthy is called a nutrient (*see page 24*).
- The groups of nutrients are carbohydrates, fats, proteins, vitamins and minerals (*see pages 24–25*).
- Each nutrient has a specific use in the body (*see pages 25–28*).
- Fibre and water are essential components of the diet (*see pages 26 and 28*).
- Different foods have different amounts of nutrients (*see page 30*).
- A balanced diet needs to be eaten for good health (*see pages 29–33*).
- Malnutrition occurs when a diet provides too few or too many nutrients (*see page 32*).
- You must eat different amounts of the different food groups to have a healthy diet (*see pages 32–33*).

End of chapter questions

1 What is a healthy diet?

2 We know that humans prefer certain foods but do animals? An investigation was done with a pair of zebra finches to find out. The zebra finches were tested with a seed mixture bought from a pet shop to see if they preferred to eat certain seeds in the mixture. A sample of the mixture was left in a dish in the birds' cage for 6 hours. At the end of that time the sample was removed and the seeds were separated into their different types. A sample of the original mixture, called the bulk, that was similar in size to the dish sample was also sorted into the different seed types.

Table 2.6 shows the composition of the two samples. Table 2.7 shows the percentage of each type of seed in the two samples.

Table 2.6

	Type A	**Type B**	**Type C**	**Type D**	**Type E**
	millet	round brown seeds	elongate grey seeds	small round seeds	black seeds
Dish	25	39	27	124	3
(total sample = 218)					
Bulk	120	27	41	97	3
(total sample = 288)					

Table 2.7

	Type A	**Type B**	**Type C**	**Type D**	**Type E**
Dish (D)	12	14	13	59	1.5
Bulk (B)	42	9	14	34	1
Difference (D – B)	–30	+5	–1	+25	–0.5

a) Why was the dish sample left for 6 hours in the birds' cage?
b) How was the test made fair?
c) Why could the figures for the seeds in the two samples in Table 2.6 not be compared directly?
d) How is the percentage of the different types of seed worked out?
e) Check the percentage of millet in both samples. How have the figures been processed?
f) If the dish sample had roughly the same composition as the bulk sample when it was first put in the birds' cage:
i) which seeds have the birds eaten most
ii) which have they most strongly avoided?
g) How could you find out more about the birds' food preferences?

3 Digestion

- The physical breakdown of food
- The chemical breakdown of food
- The role of saliva
- The oesophagus
- The stomach
- The duodenum, liver and the pancreas
- Digestion in the small intestine
- The large intestine

Your food comes from the tissues of animals and plants. To enter the cells of your body the tissues have to be broken down. This releases the nutrients (carbohydrates, fats, proteins, vitamins and minerals). Some of them are in the form of long-chain molecules. They must be broken down into smaller molecules that dissolve in water and can pass through the wall of the gut. This process of making the food into a form that can be taken into the body is called **digestion**. It takes place in the digestive system, which is made up of the **alimentary canal** and **organs** such as the liver and pancreas.

The breakdown of food

There are two major processes in the breakdown of food. They are the physical and the chemical breakdown of food. Food is physically broken down from large pieces into small pieces in the mouth. Chemical breakdown begins in the mouth and continues along the alimentary canal.

The physical breakdown of food

The teeth play a major part in the physical breakdown of food. There are four kinds of teeth. The chisel-shaped incisors are at the front of the mouth. These are for biting into soft foods like fruits. Next to the incisors are the canines. These are pointed and in dogs and cats they form the fangs that are used for tearing into tougher food like meat. Humans do not eat much tough food so they use their canines as extra incisors. The premolars and the molars are similar in appearance. They have raised parts called

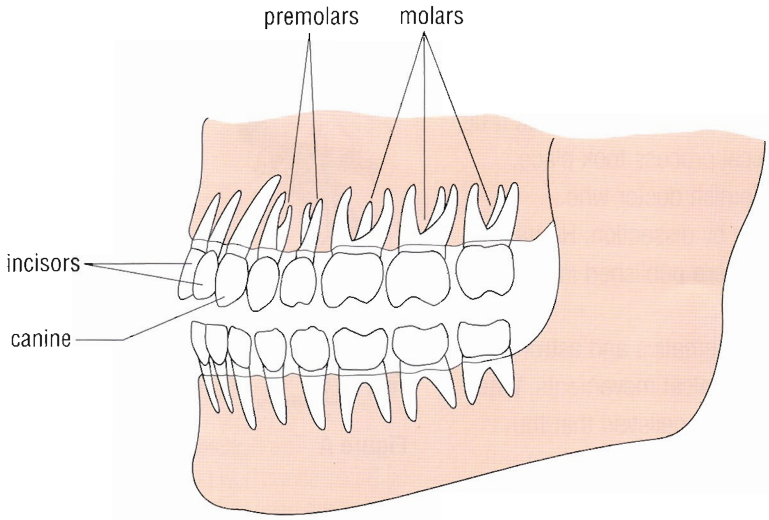


Figure 3.1 The four types of teeth in the mouth

cusps with grooves between them. They form a crushing and grinding surface at the back of the mouth. The action of the teeth breaks up the food into small pieces.

We have two sets of teeth. There are 20 teeth in the first set, called the milk teeth. The first teeth emerge through the gums at about 6 months of age and the set is complete by about age 3. It is then replaced by a second set of 32 permanent teeth which begins at about age 6 and is completed by about age 17.

1 Which smaller molecules join together to form:
   a) carbohydrates
   b) protein?
   (See also pages 24–25.)
2 What do enzymes in the digestive system do?

The chemical breakdown of food

Carbohydrates, fats and proteins are made from large molecules which consist of smaller molecules that are linked together. The large molecules do not dissolve in water and cannot pass through the lining of the digestive system into the body. The smaller molecules from which they are made, however, *do* dissolve in water and *do* pass through the wall of the digestive system. Almost all reactions in living things involve chemicals called enzymes. They are made by the body from proteins and they speed up chemical reactions. Enzymes belong to a group of chemical substances called **catalysts**. A catalyst is a substance that speeds up a chemical reaction without being changed or used up in the reaction.

Digestive enzymes speed up the breakdown of the large molecules into smaller ones. You can find out more about them on page 43.

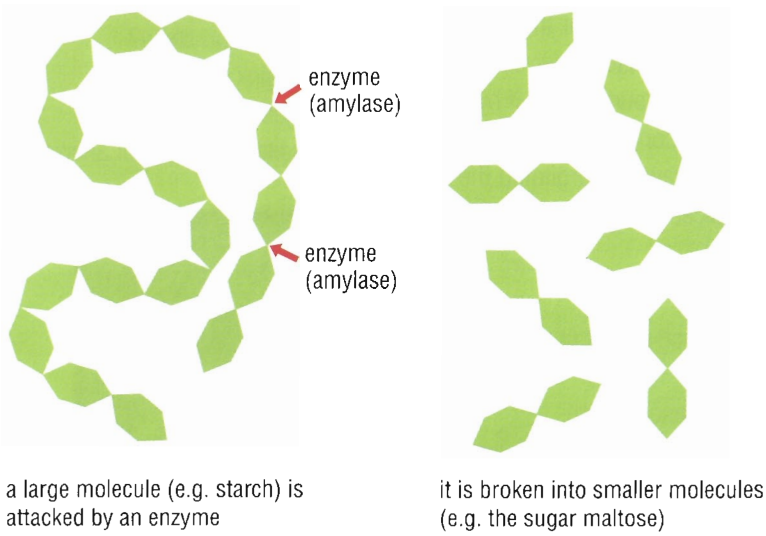


Figure 3.2 The action of an enzyme on a large food molecule

Early ideas about digestion

At one time there were two ideas about how food was digested. Some scientists believed that the stomach churned up the food to break it up physically and others believed that a chemical process took place.

Andreas Vesalius (1514–1564) was a Flemish doctor who investigated the structure of the human body by dissection. He had an artist make drawings of his work and these were published in a book for others to study.

René Descartes (1596–1650) studied mathematics and astronomy. He believed that all actions were due to mechanical movements. When he saw the drawings of Vesalius's dissections he believed that the human body behaved just as a machine.

Giovanni Borelli (1608–1679) studied the parts of the body and Descartes' ideas. He showed how muscles pulled on bones to make them move and how the bones acted as levers. This work supported Descartes' ideas and Borelli extended it to consider the stomach as a churning machine for breaking up food.

Franciscus Sylvius (1614–1672), a German doctor, believed that chemical processes took place in the body and that digestion was a chemical process that began in the mouth with the action of saliva. Some other scientists believed his ideas.

In 1752 René Réaumur (1683–1757), a French scientist, decided to test these two ideas by studying digestion in a hawk. When a hawk feeds it swallows large pieces of its prey, digests the meat and regurgitates fur, feathers and bones that it cannot digest. Réaumur put some meat inside small metal cylinders and covered the ends with a metal gauze. He fed the cylinders to the hawk and waited for the hawk to regurgitate them. He found that some of the meat had dissolved but the cylinders and gauze showed no signs of being ground up as if by a machine. To follow up his experiment he fed a sponge to the hawk to collect some of the stomach juices. When the hawk regurgitated the sponge Réaumur squeezed out the stomach juices and poured them on to a sample of meat. Slowly the meat dissolved.

6 When Descartes began to study the human body, what two pieces of evidence did he use?
7 Which activity in the 'consider ideas and evidence' stage of scientific enquiry (see page 3) did Descartes use to link the two pieces of evidence together?
8 Which pieces of evidence did Réaumer collect to help him plan his experiment with the hawk?
9 If you had been Réaumur, what prediction would you have made before feeding the hawk meat in the metal cylinder?

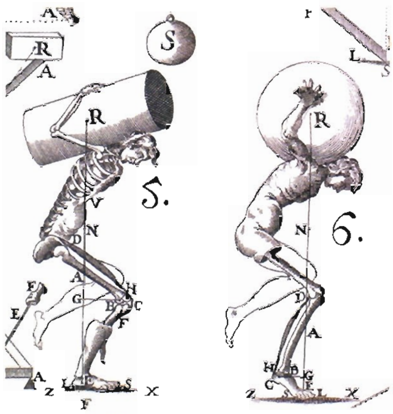


Figure A This illustration from a book by Borelli shows how he made studies of parts of the body as if it were a machine carrying a load.

1 How was Vesalius's work recorded?

2 How life-like were the recordings of Vesalius's work?
3 How did the idea that the stomach acted as a churning machine develop?
4 **a)** If Borelli's idea had been correct, what would Réaumur have found?
b) What did Réaumur's investigation show?
5 Do you think Réaumur's investigation threatened the hawk's life? Explain your answer.

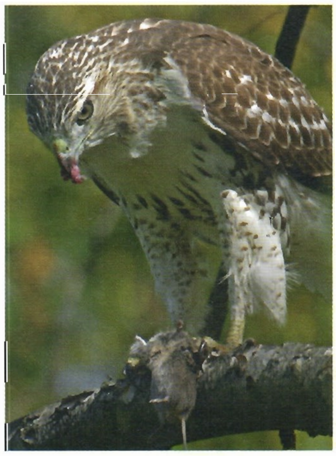


Figure B A hawk eating a meal

Along the alimentary canal

When your mouth waters

The 'water' that occurs in your mouth is called **saliva**. You can make up to 1½ litres of saliva in 24 hours. Saliva is made by three pairs of salivary **glands**. The glands are made up of groups of cells that produce the saliva and ducts (tubes) that deliver it to the mouth.

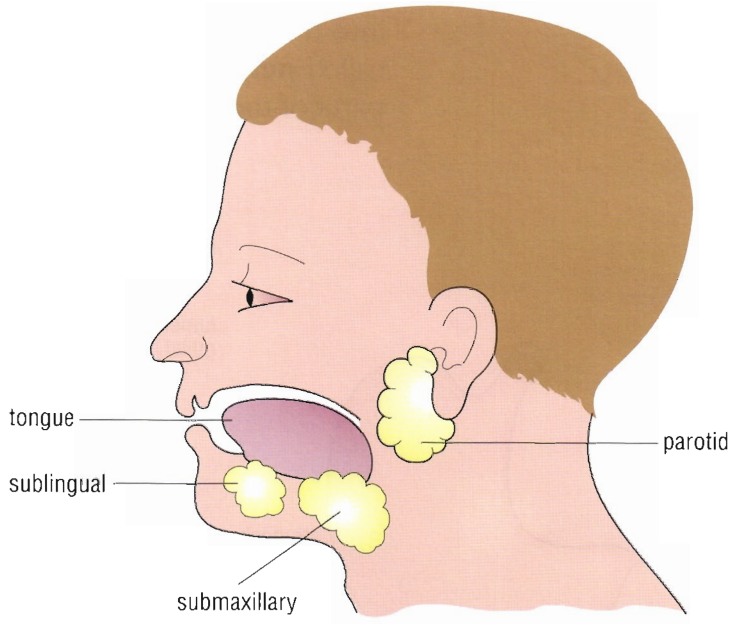


Figure 3.3 The salivary glands

Saliva is 99% water but it also contains a slimy substance called mucin and an enzyme called amylase. The mucin coats the food and makes it easier to swallow. Amylase begins the breakdown of starch molecules in the food into sugar molecules.

3 How does saliva help in digesting food?

When you swallow

When you have chewed your food it is made into a pellet called the bolus. This is pushed to the back of your mouth by your tongue. Swallowing causes the bolus to slide down your gullet, which is the tube connecting the mouth to the stomach. This tube is also called the oesophagus. It has two layers of muscles in its walls.

In the outer layer the muscle cells are arranged so that they point along the length of the gullet. These form the longitudinal muscle layer. In the inner layer the cells are arranged so that they point around the wall of the gullet. These form the circular muscle layer.

4 What is peristalsis?

5 What does hydrochloric acid do?

Muscle cells can contract (get shorter). They cannot lengthen on their own, so another set of muscle cells must work to lengthen them. In the gullet, when the circular muscles contract, they squeeze on the food and push it along the tube. The longitudinal muscles then contract to stretch the circular muscles once again. The circular muscles do not all contract at the same time. Those at the top of the gullet contract first, then a region lower down follows and so on until the food is pushed into the stomach. This wave of muscular contraction is called **peristalsis**. Peristaltic waves also occur in other parts of the alimentary canal to push the food along.

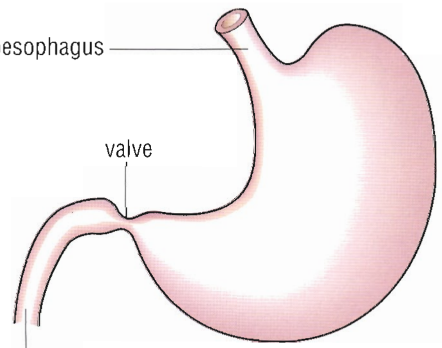


Figure 3.5 The stomach

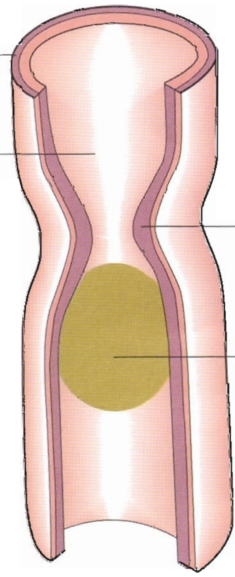


Figure 3.4 The structure of the gullet and the process of peristalsis

The stomach

The stomach wall is lined with glands. These produce hydrochloric **acid** and a protein-digesting enzyme called pepsin. The hydrochloric acid kills many kinds of bacteria in the food and provides the acid conditions that pepsin needs to start breaking down protein in the food.

The food is churned up by the action of the muscles as they send peristaltic waves down the stomach walls at a rate of about three per minute. The food is prevented from leaving the stomach by a valve. When the food is broken down into a creamy liquid the valve opens, which allows the liquid food to pass through into the next part of the digestive system.

The duodenum, liver and pancreas

The duodenum is part of the small intestine. It is connected to the stomach and two tubes open into it. One tube carries a green liquid called **bile** from the gall bladder to mix with the food. Bile is made in the liver and contains chemicals that help break down fat into small droplets so that fat-digesting enzymes can work more easily. The second tube comes from an organ called the pancreas. This is a gland that produces a juice containing enzymes that digest proteins, fats and carbohydrates. The mixture of liquids from the stomach, liver and pancreas pass on into the small intestine.

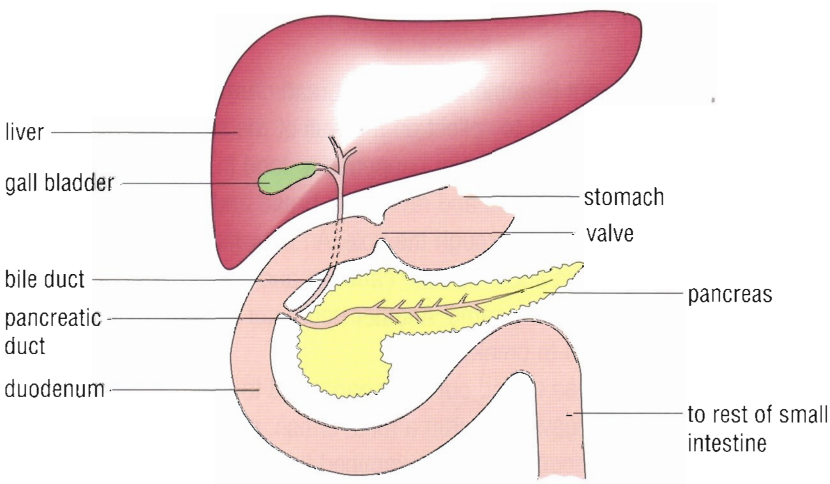


Figure 3.6 The duodenum, liver and pancreas

Digestion in the small intestine

The cells lining the wall of the small intestine make enzymes that complete the digestion of carbohydrates and proteins. Proteins are broken down into **amino acids**, carbohydrates are broken down into sugars, and fats are broken down into fatty acids and glycerol.

All these small molecules are soluble and can pass through the wall of the small intestine. They are carried by the blood to all cells of the body.

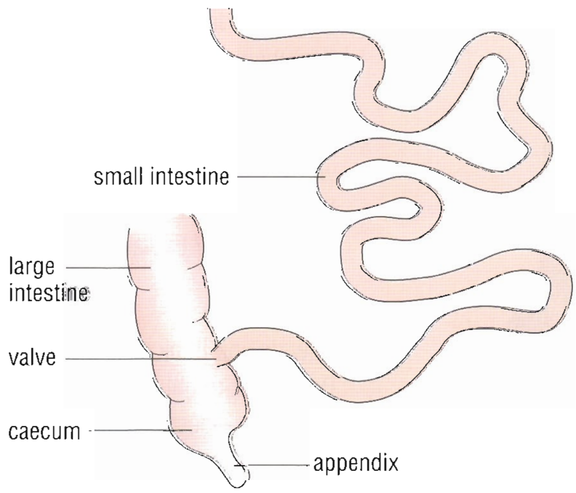


Figure 3.7 The small intestine and its connection to the large intestine

6 Where is bile made and what does it do?
7 What are proteins, fats and carbohydrates broken down into?
8 Where are the digested foods absorbed?

A hole in the stomach

In 1822 a group of fur trappers and hunters gathered at a trading post, Fort Mackinac, in North America. One of the hunters accidentally fired his gun and shot a 19-year-old man called Alexis St Martin. It was fortunate that Doctor William Beaumont (1785–1853) was close by and could attend to the wounded man and save his life. St Martin had lost some flesh from over his stomach and part of the stomach wall. The wound did not completely heal. It formed a flap over the stomach which could be opened and the contents of the stomach examined.

St Martin agreed to help Beaumont to find out what happened inside the stomach during digestion. First Beaumont asked St Martin to eat nothing for a few hours. Then he looked inside the stomach and found that the stomach contained saliva, which St Martin had swallowed, and some mucus from the stomach wall.

In another experiment Beaumont put some bread crumbs into the stomach and saw digestive juice start to collect on the wall of the stomach.

Beaumont wanted to find out what happened to food in the stomach. So he fastened pieces of cooked and raw meat, bread and cabbage onto silk strings and pushed them through the hole. An hour later he pulled the strings out and found that about half the cabbage and bread had broken up but the meat remained the same. Another hour later he found that the cooked meat had started to break down.

Next Beaumont wanted to find out what happened to the food after St Martin had eaten it. He gave St Martin a meal of fish, potatoes, bread and parsnips. After half an hour Beaumont examined the stomach contents and found that he could still identify pieces of fish and potato. After another half hour pieces of potato could still be seen but most of the fish had broken up. One and a half hours after the meal all the pieces of the food had broken up. Two hours after the meal the stomach was empty.

Figure C Doctor Beaumont placing a piece of food into Alexis St Martin's stomach

10 In the first experiment Beaumont was interested to find out if the stomach contained digestive juices all the time, even when no food was present.

a) What conclusion could he draw from his observation?

b) What prediction could he make from this observation?

11 What do you think Beaumont concluded from his second experiment?

12 The juices contain important chemicals made by the body. What are these called?

13 What do you think Beaumont concluded from his experiments with food on strings?

14 What do you think Beaumont concluded from his experiment on St Martin's meal?

15 Beaumont also investigated the action of the stomach juice outside the stomach. Why would he have kept the juice at body temperature?

16 If you were Alexis St Martin would you have allowed Dr Beaumont to carry out his investigation? Explain your reasons.

17 How do you think Beaumont might have explained digestion using his knowledge and understanding?

The fate of undigested food

Indigestible parts of the food, such as cellulose, pass on through the small intestine to the large intestine and colon. The first part of the large intestine is called the caecum. This is attached to a much longer part called the colon. Here water and some dissolved vitamins are absorbed and taken into the body. The remaining semi-solid substances form the faeces. These are stored in the last part of the large intestine, which is called the rectum. The faeces are removed from the body through the anus, perhaps once or twice a day, in a process called **egestion** or defecation.

9 What happens to undigested food in the large intestine?

10 What happens during egestion?

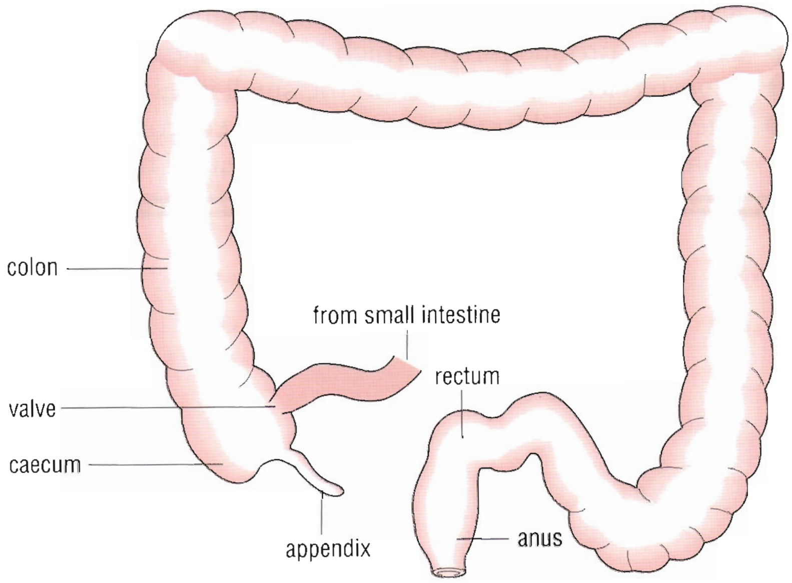


Figure 3.8 The large intestine

11 What type of enzyme is produced in:
a) the mouth
b) the stomach?

12 What type of enzyme does bile help?

13 Where does bile come from?

14 Which organ of the digestive system produces all three types of enzyme?

15 Why do small droplets of fat get broken down by enzymes more quickly than large droplets?

Enzymes

An enzyme that digests carbohydrate is called a carbohydrase. An enzyme that digests protein is called a protease. An enzyme that digests fat is called a lipase.

Table 3.1 Enzymes

Region of production	Type of enzyme	Notes
salivary glands in mouth	carbohydrase	• enzyme is called salivary amylase
gastric glands in stomach	protease	• enzyme is called pepsin • hydrochloric acid is also made to help the enzyme work
pancreas	protease, carbohydrase, lipase	• enzymes enter the duodenum and mix with food and bile

SUMMARY

- There are four kinds of teeth: incisors, canines, premolars and molars. They have special shapes for specific tasks (*see pages 36–37*).
- The purpose of digestion is to break down the food into substances that can be absorbed and used by the body (*see page 37*).
- Enzymes break down the large molecules in food into smaller molecules so that they can be absorbed by the body (*see page 37*).
- The food is moved along the gut by a wave of muscular contraction called peristalsis (*see page 40*).
- The food is digested by enzymes that are made in the salivary glands, the stomach wall, the pancreas and the wall of the small intestine (*see pages 39–41 and 43*).
- The liver produces bile, which helps in the digestion of fat (*see page 41*).
- Digested food is absorbed in the small intestine (*see page 41*).
- The undigested food has water removed from it in the large intestine and is then stored in the rectum before being released through the anus (*see page 43*).

End of chapter questions

1 Collect a copy of Figure 3.9 from your teacher and use the other diagrams in this chapter to label the parts of the digestive system.

2 Describe the digestion of a chicken sandwich.

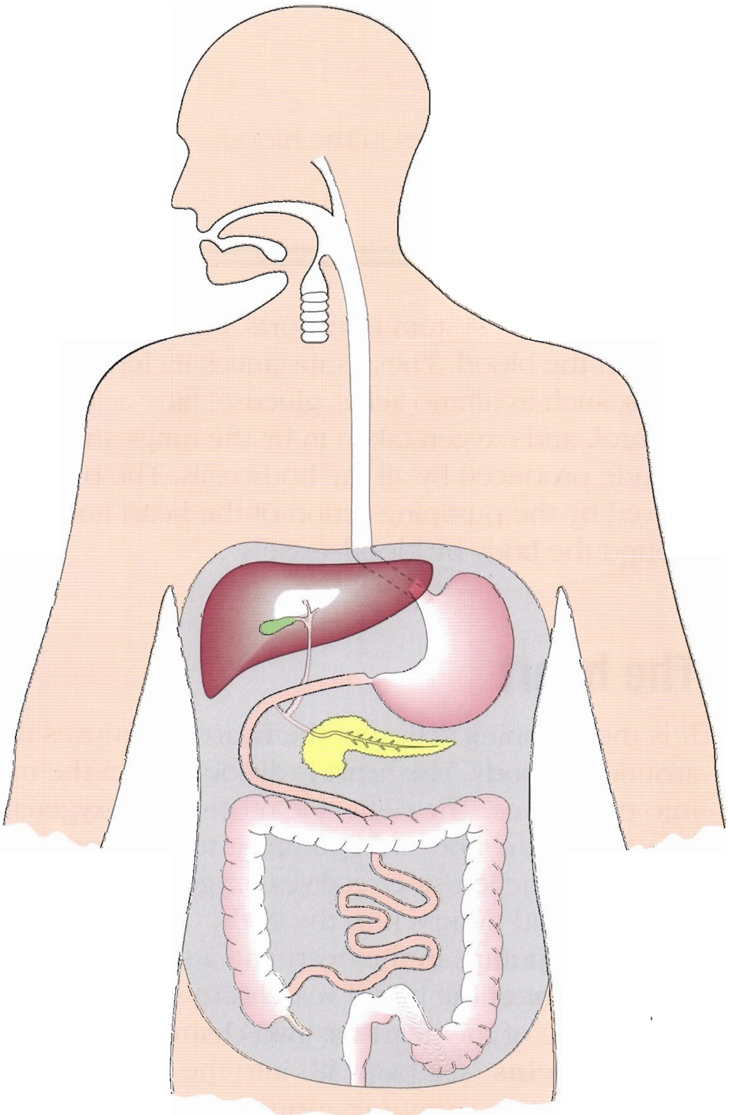


Figure 3.9 The digestive system

4 The circulatory system

- The heart
- Blood vessels
- Blood
- Moving substances in the blood
- A healthy heart
- Exercise

The circulatory system transports substances around the body in the blood. These substances include digested foods, such as amino acids, glucose, fatty acids and glycerol, and oxygen taken in by the lungs and carbon dioxide produced by all the body cells. The blood is moved by the pumping action of the heart and directed around the body by blood vessels.

The heart

It is the pumping action of the heart that moves the blood around the body. The heart is divided down the middle into two halves. The right side receives deoxygenated blood from the body and pumps it to the lungs. At the same time the left side receives oxygenated blood from the lungs and pumps it to the body.

The two pumps in the heart and a simplified arrangement of the blood vessels are shown in Figure 4.1.

Each side of the heart has two chambers. Blood flows from the **veins** (see page 48) into the upper chambers, called the **atria** (*singular:* atrium). It passes from the atria into the lower chambers, called the **ventricles**.

The muscular walls of the ventricles relax as they fill up. When these muscular walls contract the blood is pumped into the **arteries** (see page 47). Valves between the atria and the ventricles stop the blood going backwards into the atria. Valves between the arteries (the aorta and the pulmonary artery) and the ventricles stop the blood from flowing backwards after it has been pumped out of the heart.

1 Where does the pushing force come from to push the blood out of the heart?
2 What is the purpose of the heart valves?
3 Why do you think the walls of the left ventricle are thicker than the walls of the right ventricle?

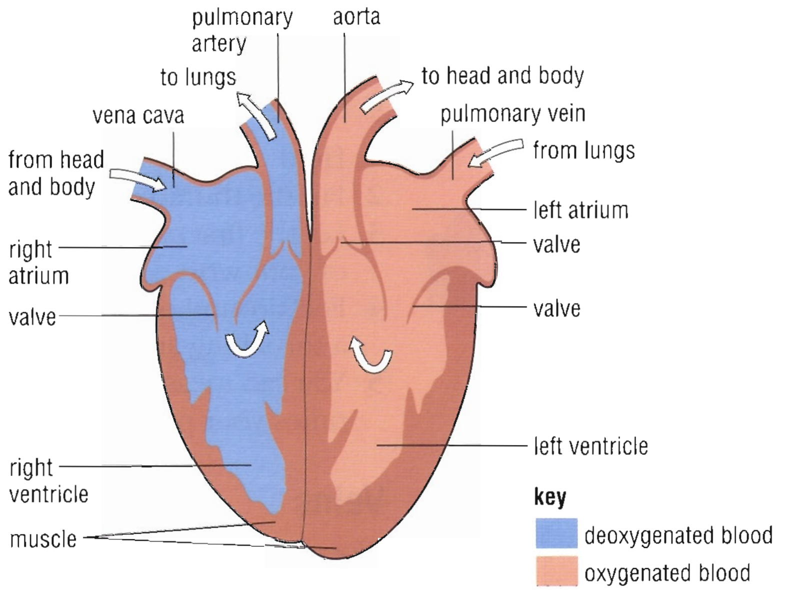


Figure 4.1 A simplified section through the heart

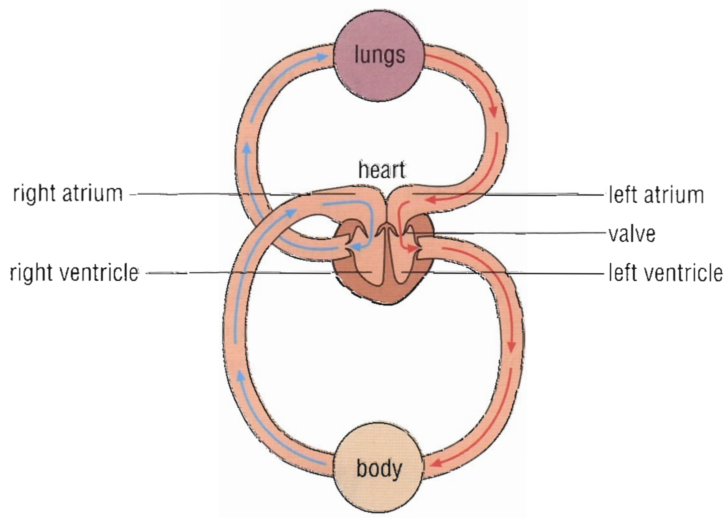


Figure 4.2 A simplified path of the blood through the circulatory system

Blood vessels

Arteries

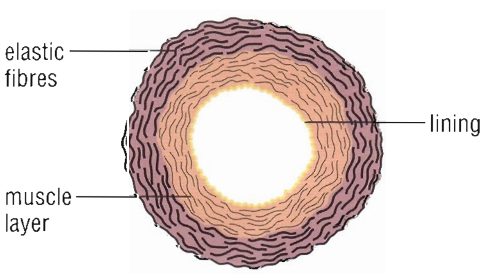


Figure 4.3 A cross-section through an artery

Blood vessels that take blood away from the heart are called arteries. The high pressure of blood pushes strongly on the thick, elastic artery walls. They stretch and shrink as the blood moves through them. This movement of the artery wall makes a pulse. When an artery passes close to the skin the pulse can be felt and therefore used to count how fast the heart is beating.

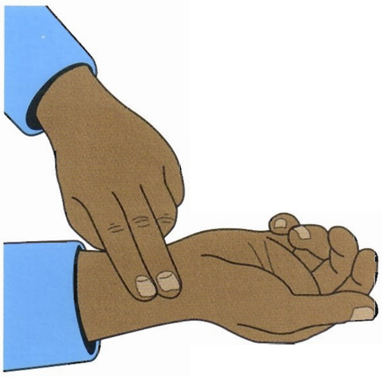


Figure 4.4 Measuring a pulse

Measuring a pulse

You learnt how to measure your pulse rate last year. Here is a reminder.

1 Hold out your right hand with the palm up.
2 Put the thumb of your left hand under your wrist.
3 Let the first two fingers of your left hand rest on the top of your wrist.
4 Feel around on your wrist with these two fingers to find a throbbing artery. This is your pulse.
5 You can measure your pulse rate by counting how many times your pulse beats in a minute.

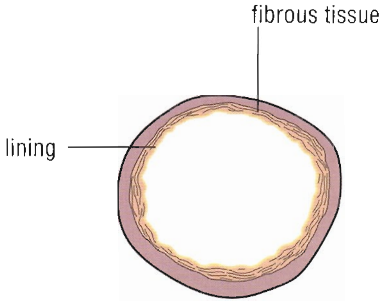


Figure 4.5 A cross-section through a vein

4 Why do veins have valves?
5 Why do you think arteries function better with thick walls?

Veins

Blood vessels that bring blood towards the heart are called veins. The blood is not under such high pressure and so does not push as strongly on the vein walls. Veins have thinner walls than arteries and contain valves that stop the blood flowing backwards.

Capillaries

When an artery reaches an organ it splits into smaller and smaller vessels. The smallest blood vessels are called **capillaries**. A capillary wall is only one cell thick. Capillaries are spread throughout the organ so that all cells have blood passing close to them. Where the blood leaves an organ, capillaries join together to form larger and larger vessels until eventually they form veins.

What is in the blood?

About 45% of a drop of blood is made from cells. There are two kinds, red cells and white cells.

Red cells contain **haemoglobin**, which transports oxygen from the lungs to the other body cells. Haemoglobin allows the blood to carry 100 times more oxygen than the same amount of water. There are 500 red cells for every white cell.

6 Could you live without haemoglobin? Explain your answer.
7 Compare the tasks of red and white blood cells.

White cells fight disease. They attack bacteria and produce chemicals to stop virus infections. White cells also gather at the site of a wound where the skin has been cut. They eat bacteria that try to enter the body. The white cells die in this process and their bodies collect to form pus in the wound.

The blood also carries **platelets**, which are fragments of cells. These collect in the capillaries at the site of a wound and act to block the flow of blood. Platelets help the blood to form clots at the site of a wound. These clots stop blood leaking out of the wound.

About 55% of blood is a watery liquid called **plasma**. This contains digested foods, hormones, a waste product from the liver called urea and the carbon dioxide produced by all the body cells.

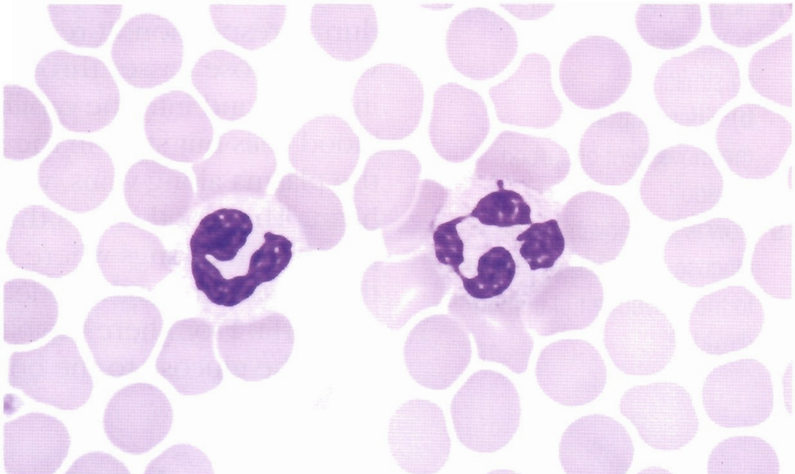


Figure 4.6 Red blood cells and two highly stained white blood cells

Moving oxygen to the cells

Once oxygen has entered the red blood cells it begins its journey inside the body. It starts by moving through the capillaries in the lungs. Capillaries are just one of three kinds of blood vessels found in the body (the other two are arteries and veins). They make a network of fine tubes in organs which provide a very large surface area between the blood and the tissues in the organs. This surface area allows large amounts of substances, such as oxygen and glucose, to pass between the blood and the tissues in a short amount of time. When the blood moves away from the lungs, it travels along a larger blood vessel called the pulmonary vein. The oxygenated blood is transported to the heart in the pulmonary vein and is then circulated around the body.

Moving carbon dioxide to the lungs

Carbon dioxide is a product of aerobic respiration. It leaves the cells where it is produced and passes through the walls of the capillaries. Carbon dioxide does not enter the red blood cells but stays in the yellow watery part of the blood called the plasma. It travels along veins which take it back to the right side of the heart. From here carbon dioxide enters the pulmonary artery and travels to the lungs. It escapes through the capillary walls into the air in the alveoli (see gaseous exchange page 59).

Moving glucose to the cells

8 How is the movement of oxygen in the body:
a) similar to
b) different from
the movement of carbon dioxide?

9 How is the movement of glucose in the blood similar to the movement of carbon dioxide?

Glucose contains the store of energy that is released during respiration. It reaches the cells in the following way. Glucose passes through the wall of the small intestine and into the capillaries. It does not enter the red blood cells but stays in the plasma. The glucose travels in the plasma along veins, which bring the blood to the heart. The blood enters the right side of the heart, then passes to the lungs where it picks up oxygen. The blood then passes through the left side of the heart, and into the aorta. From here the blood travels along arteries and takes the glucose to the body organs.

A healthy heart

The heart may beat up to 2500 million times during a person's life. Its function is to push blood around the 100 000 km of blood vessels in the body. This push creates a blood pressure that drives the blood through the blood vessels. As the ventricles in the heart fill with blood the pressure in the blood vessels is reduced but as the heart pumps it out along the arteries the blood pressure rises. The walls of the arteries are elastic and they stretch and contract with the blood pressure. In young people the arteries are free from obstructions and their diameters are large enough to let the blood flow with ease. As the body ages the artery walls become less elastic.

Studies on the circulatory system

Erasistratus (about 304–250 BCE) was a Greek doctor who studied the circulatory system. He suggested that veins and arteries carried different substances. He thought that veins carried blood and arteries carried 'animal spirit'.

Galen (about 130–200 BCE) was also a Greek doctor. He used the pulse of patients to help him to assess their sickness. He realised that the blood from one side of the heart got to the other side but he did not know how it happened. He thought there were tiny holes in the wall between the two sides of the heart. Galen also thought that the blood went backwards and forwards along the blood vessels. His ideas were held in high regard for over 1400 years.

Michael Servetus (1511–1553) was a Spanish doctor who traced the path of blood to and from the heart along the vein and artery that go to and from the lungs. He did not think that the blood went into the heart's muscular walls.

Fabricius ab Aquapendente (1537–1619) was a professor of surgery who discovered that the veins had valves in them. He taught the Englishman William Harvey (1578–1657) who became a doctor and went on to do further studies of the circulatory system. Fabricius's discovery of the valves gave Harvey a clue as to how the blood might flow. He followed up Fabricius's discovery by blocking an artery by tying a cord around it. He found that the side towards the heart swelled up because of the collecting blood. Next, he tied a cord around a vein. He found that the vein swelled on the side away from the heart.

Harvey also calculated the mass of blood that the heart pumped out in an hour. It was three times the mass of a man, yet the body did not increase in size. One explanation was that the heart made this amount of blood in an hour and another organ in the body destroyed it so the body did not increase in size. Harvey thought it impossible for the blood to be made and destroyed so quickly and so suggested that the blood must move around the body in only one direction. He published his ideas in a book in 1628 and was mocked by other doctors for challenging the ideas of Galen.

Eventually the idea of the blood circulating round the body was accepted but Harvey could not explain how the blood got from the arteries to the veins.

Marcello Malpighi (1628–1694) was an Italian scientist who studied the wing of a bat under a microscope. He found that there was a connection between the arteries and veins in the wing. These were tiny vessels that could not be seen with the eye. These vessels were called capillaries and the blood could be seen flowing through them.

Figure A William Harvey at work

1 Who first described arteries and veins?

2 Who first began to doubt Galen's ideas?

3 How did Fabricius's discovery help Harvey?

4 If the blood flowed as Galen suggested, what would Harvey have found when he tied cords around the artery and the vein?

5 How did Harvey interpret his observations?

6 Why was Harvey's idea ridiculed?

7 How did Malpighi's work support Harvey's ideas?

8 What evidence did Harvey consider when he planned his investigation on the flow of blood?

9 Which activity in 'considering evidence and approach' (see page 4) did Harvey use when he found the mass of blood pumped in an hour was three times the mass of a man?

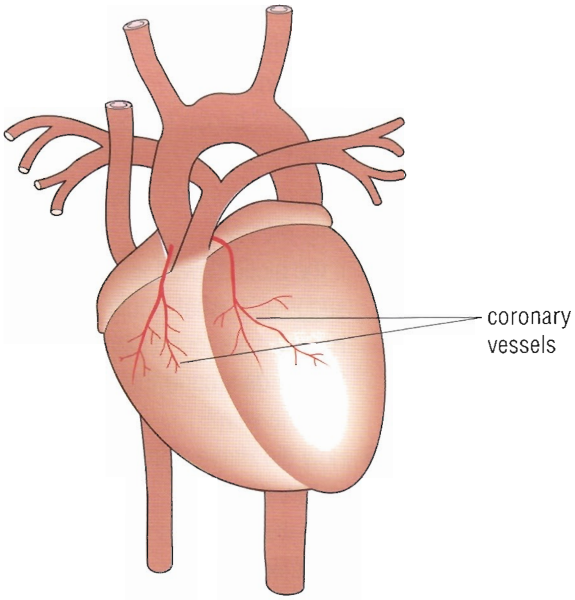


Figure 4.7 The coronary blood vessels

The heart has its own blood vessels called the coronary arteries and veins. The coronary blood vessels are shown in Figure 4.7. They transport blood to and from the heart muscle.

Fatty substances, such as cholesterol, stick to the walls of arteries. Calcium settles in the fatty layer and forms a raised patch called an atheroma. The blood then has less space to pass along the arteries and its pressure rises as it pushes through the narrower tubes. Other components of the blood, such as platelets, settle on the atheroma and make it larger. This may cause a blood clot which narrows the artery even more or can completely block it, causing a thrombosis. This means that the artery is unable to supply oxygen and other nutrients to the relevant organ. A thrombosis in a coronary artery causes a heart attack. A thrombosis in an artery in the brain causes a stroke.

The features that develop in the body that cause heart disease can be inherited. People whose relatives have suffered from heart disease should take special care to keep their heart and circulatory system healthy.

Keeping the heart healthy

The heart is made of muscle and, like all muscles, it needs exercise if it is to remain strong. The heart muscles are exercised when you take part in the activities in Table 4.1 (see page 53). Heart muscle contracts more quickly and more powerfully during exercise than it does at rest so that more blood can be pumped to your muscles. These muscles need more blood to provide them with extra oxygen while they work.

As we have seen, the blood supply to heart muscles can be reduced by fatty substances such as cholesterol in the blood. These substances are formed after the digestion of fatty foods. Some fatty substances are needed to keep the membranes of the cells healthy but eating too much fat leads to heart disease. A heart can be kept healthy by cutting down on the amount of fat in the diet. This may be achieved by cutting fat off meat or eating fewer crisps and chips, for example.

For discussion

How could a campaign for 'keeping your heart healthy' be carried out in your school? How could you assess if the campaign had been a success?

10 Which activities demand great flexibility?
11 Which activity is the least demanding?
12 Which activities are the most demanding?
13 How do the demands of soccer and long distance running compare?
14 Which activity would you choose from Table 4.1? What are its strengths and weaknesses?

15 Many people claim that they do not have time to exercise. How would you motivate such people to take some form of exercise? Which activities might suit them best?

If large amounts of fat are eaten the fat is stored in the body. In time, a person who eats a diet high in fat will become obese. This puts extra strain on the heart as it tries to push the blood to the greatly enlarged body. The extra strain on the heart and the build up of fatty substances in the coronary artery can cause the heart muscle to fail and the person has a heart attack. Obesity can be avoided by eating a balanced diet (see page 32) and using the pyramid of food (see page 33) as a guide.

Exercise

Regular exercise makes many of the organ systems become more efficient. It also uses up energy and helps to prevent large amounts of fat building up in the body. Exercise can increase your fitness in three ways: it can improve your strength, it can make your body more flexible and less likely to suffer from sprains and it can increase your endurance, which is your ability to exercise steadily for long periods without resting. Different activities require different levels of fitness. Table 4.1 shows these levels for different sporting activities. By studying the table you can work out which activities you could do to develop one or more of the three components of fitness.

Figure 4.8 Playing a team sport like soccer is a great way to develop your strength, flexibility and endurance, and have a lot of fun at the same time!

Table 4.1

Activity	Strength	Flexibility	Endurance
basketball	✓✓	✓✓	✓✓✓
dancing	✓✓	✓✓✓	✓✓
golf	✓✓	✓✓	✓✓
long distance running	✓✓✓	✓✓	✓✓✓
soccer	✓✓	✓✓	✓✓✓
squash	✓✓✓	✓✓✓	✓✓✓
swimming	✓✓✓	✓✓	✓✓✓
tennis	✓✓✓	✓✓✓	✓✓✓
walking	✓	✓	✓✓

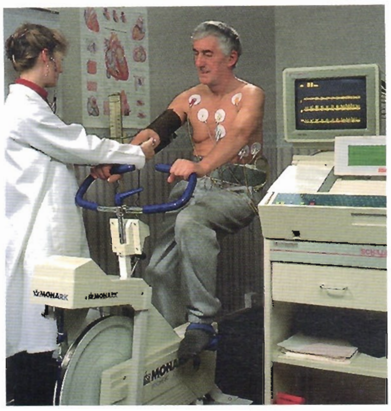


Figure 4.9 Pedalling an exercise bicycle makes the heart beat faster to provide blood for the leg muscles.

Care with exercise

When people decide to get fit, they may choose one of the activities from Table 4.1 and begin with great enthusiasm. However, they may experience a sprain or pains by trying to exercise too hard too early. The skeleton and muscles work together to provide movement.

Someone who has not been active for a long time may need to build up their exercises gradually so that the muscles and joints can become adapted to the increased activity. If this is not done and someone receives an injury early on in their exercise programme they may decide not to continue and they will become unfit again. It can help to be aware of how the skeleton and muscles work and to think of them when an exercise programme is begun.

SUMMARY

- The heart contains two pumps for moving blood (*see page 46*).
- The three kinds of blood vessels are arteries, veins and capillaries (*see pages 47–48*).
- Blood is composed of plasma, cells and platelets (*see pages 48–49*).
- Oxygen travels through the blood in the red blood cells (*see page 49*).
- Carbon dioxide travels through the blood in the plasma (*see page 50*).
- Glucose travels through the blood in the plasma (*see page 50*).
- Diet can affect the supply of blood to the heart (*see pages 52–53*).
- Regular exercise makes organ systems more efficient (*see page 53*).
- Different activities for exercise need different levels of fitness (*see page 53*).

End of chapter questions

1 Four people took their pulse (measured in beats per minute, on a portable heart monitor) at rest, straight after exercise, one minute after exercise, two minutes after exercise and three minutes after exercise.
Here are their results.
Anwar: 71, 110, 90, 79, 71
Baylee: 74, 115, 89, 77, 73
Chiumbo: 73, 125, 115, 108, 91
Daisy: 53, 80, 71, 46, 84
a) Make a table of the results.
b) Plot a graph of the results.
c) What trend can you see in the results?
d) When did Anwar and Baylee's hearts beat at the same rate?
e) Anwar claims to be fitter than Chiumbo. Do you think the results support his claim? Explain your answer.
f) Which result does not follow the trend? Explain why this may be so.

2 Which substance does regular exercise prevent building up in the body?

5 The respiratory system

- The parts of the respiratory system
- The air passages and tubes
- The air pump
- Breathing movements
- Gaseous exchange
- Respiration
- Smoking and health

In Chapter 3 we saw how food is broken down in the digestive system in readiness for transport to the cells. In this section we look at how the respiratory system provides a means of exchanging the respiratory gases – oxygen and carbon dioxide.

Breathing and respiration

The terms respiration and **breathing** are often confused but they do have different meanings. Breathing describes just the movement of air in and out of the lungs. Respiration covers the whole process by which oxygen is taken into the body, transported to the cells and used in a reaction with glucose to release energy, with the production of water and carbon dioxide as waste products.

The parts of the respiratory system

The function of the respiratory system is to provide a means of exchanging oxygen and carbon dioxide that meets the needs of the body, whether it is active or at rest. In humans the system is located in the head, neck and chest. It can be divided into three parts: the air passages and tubes, the pump that moves the air in and out of the system, and the respiratory surface.

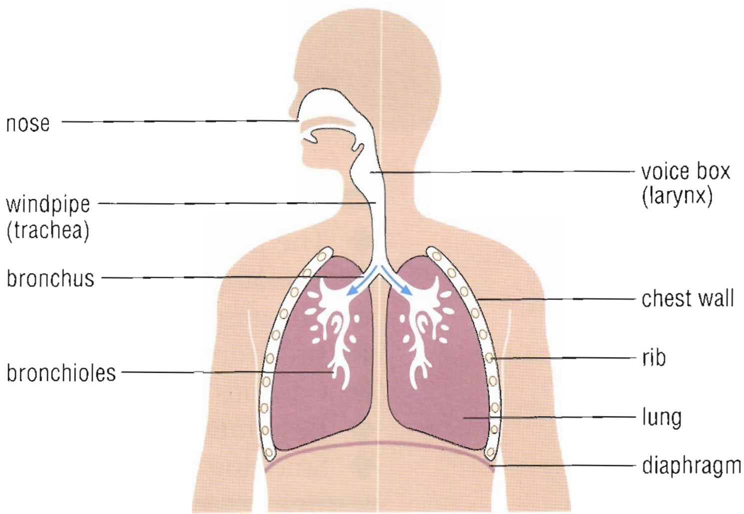


Figure 5.1 The respiratory system

The air passages and tubes

The nose

Air normally enters the air passages through the nose. Hairs in the nose trap some of the dust particles that are carried in the air currents. The lining of the nose produces a watery liquid called mucus. This makes the air moist as it passes inwards and also traps bacteria that are carried on the air currents. Blood vessels beneath the nasal lining release heat that warms the air before it passes into the lungs.

The windpipe

The windpipe or trachea is about 10 cm long and 1.5 cm wide. It is made from rings of cartilage, which is a fairly rigid substance. Each ring is in the shape of a 'C'. The inner lining of the windpipe has two types of cells. They are mucus-secreting cells and ciliated epithelial cells. Dust particles and bacteria are trapped in the mucus.

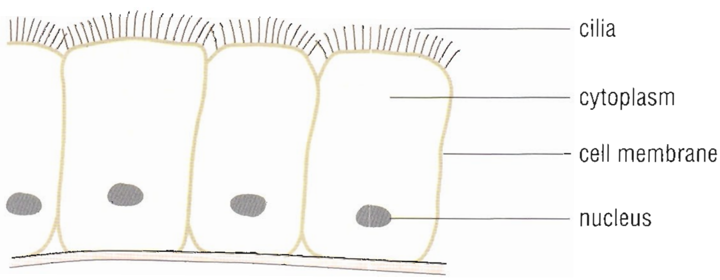


Figure 5.2 Ciliated epithelial cells

The cilia are microscopic hairs which beat backwards and forwards to move the mucus to the top of the windpipe where it enters the back of the mouth and is swallowed.

The bronchi and bronchioles

The windpipe divides into two smaller tubes called bronchi. (This is the name for more than one tube. A single tube is called a bronchus.) The two bronchi are also made of hoops of cartilage and have the same lining as the windpipe.

The bronchi divide up into many smaller tubes called bronchioles. These have a diameter of about 1 mm.

The bronchioles divide many times. They have walls made of muscle but do not have hoops of cartilage. The wall muscles can make the diameter of the bronchioles narrower or wider.

Some people suffer from asthma. They may be allergic to certain proteins in food or to the proteins in dust that come from fur and feathers. The presence of these proteins in the air affects the muscles in the bronchioles and the air passages in the bronchioles become narrower. This makes breathing very difficult. A person suffering an asthmatic attack can use an inhaler that releases chemicals to make the muscles relax to widen the bronchioles.

1 What structures hold the air passages open in the windpipe and bronchi?
2 Why is it more difficult to breathe during an asthmatic attack?

The air pump

The two parts of the air pump are the chest wall and the diaphragm. They surround the cavity in the chest. Most of the space inside the chest is taken up by the lungs. The outer surfaces of the lungs always lie close to the inside wall of the chest. The small space between the lungs and the chest wall is called the pleural cavity. This cavity contains a film of liquid that acts like a lubricating oil, helping the lung and chest wall surfaces to slide over each other during breathing.

3 Why is there a film of liquid in the pleural cavity?

The chest wall

This is made by the ribs and their muscles. Each rib is attached to the backbone by a joint that allows only a small amount of movement. The muscles between the ribs are called the internal and external intercostal muscles. The action of these muscles moves the ribs.

The diaphragm

This is a large sheet of muscle attached to the edges of the tenth pair of ribs and the backbone. It separates the chest cavity, which contains the lungs and heart, from the lower body cavity, which contains the stomach, intestines, liver, kidneys and female reproductive organs.

Breathing movements

There are two breathing movements: inspiration and expiration. The actions that take place in each one are shown in Figure 5.3 and summarised in Table 5.1.

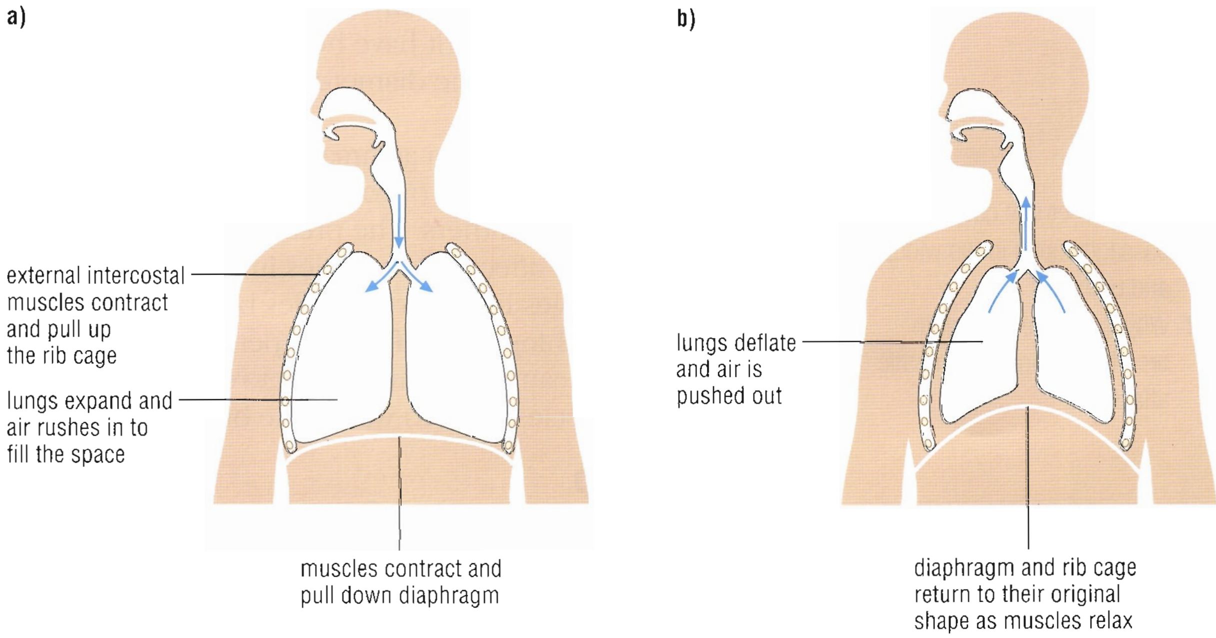


Figure 5.3 a) Inspiration **b)** Expiration

Table 5.1 Inspiration and expiration

Breathing movement	Inspiration	Expiration
external intercostal muscles	contract	relax
rib action	move up	move down
diaphragm muscles	contract	relax
diaphragm action	moves down and becomes flatter	moves up and becomes dome shaped
change in chest volume	increases	decreases
air	moves in	moves out

4 How does the action of the external intercostal muscles and the diaphragm muscles draw air up your nose?

5 How do the values of the tidal volume and vital capacity compare?

6 **a)** A resting person gets up and starts running. Describe two ways in which the person's breathing pattern changes.

b) Why should a person's breathing pattern change between resting and running?

Depth of breathing

The amount of air breathed in and out at rest is called the tidal volume and is about 500 cm^3 in humans. The maximum amount of air that can be breathed in and out is called the vital capacity. In human adults the vital capacity may reach 4000 cm^3.

Gaseous exchange

At the end of each bronchiole is a very short tube called the alveolar duct. Bubble-like structures called alveoli open into this duct. Each alveolus has a moist lining, a thin wall and is supplied with tiny blood vessels called capillaries. The alveoli form the respiratory surface and this is where **gaseous exchange** takes place.

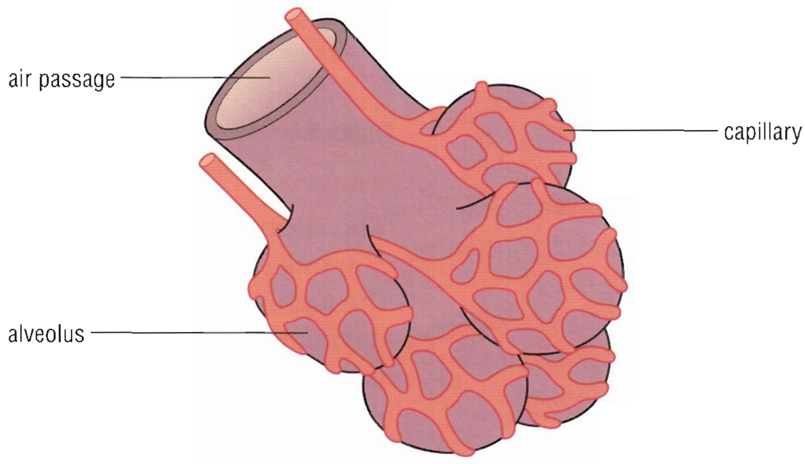


Figure 5.4 An alveolus

Oxygen from the inhaled air dissolves in the moist alveolar lining and moves by diffusion through the walls of the alveolus and the capillary next to it. The oxygen diffuses into the blood and enters the red blood cells (see page 48), which contain a dark red substance called haemoglobin. The oxygen then combines with the haemoglobin to make **oxyhaemoglobin**, which is bright red. Blood that has received oxygen from the air in the lungs is known as oxygenated blood.

Carbon dioxide is dissolved in the watery part of the blood called the plasma. It moves by diffusion through the capillary and alveolar walls and changes into a gas as it leaves the moist lining of the alveolus.

Blood moves through the capillaries very quickly, so a large amount of oxygen and carbon dioxide can be exchanged in a short time.

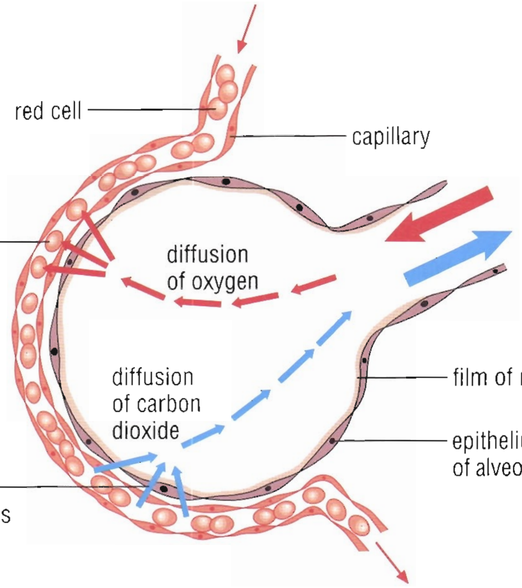


Figure 5.5 Diagram to show the direction of gaseous exchange

7 How would thick-walled alveoli affect the exchange of the respiratory gases?

8 Haemoglobin contains the mineral iron which the body gets from food. How would eating a diet deficient in iron affect the amount of oxygen taken up by the blood?

9 How do you think you would be affected if the surface area of your lungs was reduced?

The spongy structure of the lungs is produced by the 300 million alveoli which make a very large surface area through which the gases can be exchanged. It is like having the surface area of a tennis court wrapped up inside two footballs! If this surface area is reduced then health suffers.

Respiration

The name 'respiratory system' suggests that this is the part of the body where respiration takes place. This is wrong because respiration takes place in every cell in the body.

The respiratory system does, however, provide the means for all the cells to respire efficiently. It extracts oxygen from the air and releases carbon dioxide from the body.

Life processes occur in every cell. One example of a life process is the building up of proteins from amino acids produced by digestion. The proteins are used to make or repair structures such as the cell membrane and to make enzymes, which help chemical reactions take place inside the cell.

All life processes require energy. The energy is stored in food molecules and is released by respiration. In the human body the sugar glucose is the main source of energy. Most of it is formed from the digestion of starch. The energy in the sugar molecules is released in one of two kinds of respiration.

Aerobic respiration

In this process energy is released when sugar molecules take part in a chemical reaction with oxygen. In this reaction carbon dioxide and water are produced. This reaction can be can be written as a word equation:

glucose + oxygen → carbon dioxide + water

Anaerobic respiration

This process occurs when the body cannot get enough oxygen for aerobic respiration to take place. For example, when you sprint you cannot breathe fast enough to get the oxygen you need to release energy for your muscles. The body responds by releasing the energy anyway in a process called anaerobic respiration and other substances are made. These must be broken down by aerobic respiration so when your sprint is over you breathe in large quantities of air quickly to provide the oxygen that is needed.

10 What are the life processes that take place to show that an organism is alive?

11 When you walk you breathe steadily. What kind of respiration is taking place in your muscles? Explain your answer.

Smoking and health

We have seen how the respiratory system works to allow us to exchange respiratory gases. An efficient exchange is needed for good health. When people smoke they damage their respiratory system and risk seriously damaging their health.

There are over a thousand different chemicals in cigarette smoke, including the highly addictive nicotine.

These chemicals swirl around the air passages when a smoker inhales and touch the air passage linings. In a healthy person, dust particles are trapped in mucus and moved up to the throat by the beating of microscopic hairs called cilia. The small amounts of dust and mucus are then swallowed. In a smoker's respiratory system the cilia stop beating because of chemical damage by the smoke. More mucus is produced but instead of being carried up by the cilia it is coughed up by a jet of air as the lungs exhale strongly. This is a smoker's cough and the amount of dirty mucus reaching the throat may be too much to swallow.

12 What is the function of a smoker's cough?

13 Why may chronic bronchitis lead to other diseases?

14 How does the reduced number of alveoli affect the exchange of oxygen and carbon dioxide?

15 Why does someone with emphysema breathe more rapidly than a healthy person?

In time chronic bronchitis may develop. The lining of the bronchi becomes inflamed and open to infection from microorganisms. The inflammation of the air passages makes breathing more difficult and the smoker develops a permanent cough. The coughing causes the walls of some of the alveoli in the lungs to burst. When this happens the surface area of the lungs in contact with the air is reduced. This leads to a disease called emphysema.

Figure 5.6 People with lung damage from smoking need extra oxygen and regular checks on their lungs.

For discussion

Should a person who becomes ill through having an unhealthy lifestyle receive the same amount of medical attention as someone who has had an accident?

Some of the cells lining the air passages are killed by the chemicals in the smoke. They are replaced by cells below them as they divide and grow. Some of these cells may be damaged by the smoke too and as they divide they may form cancer cells. These cells replace the normal cells in the tissues around them but they do not perform the functions of the cells they replace. The cancer cells continue to divide and form a lump called a tumour. This may block the airway or break up and spread to other parts of the lung where more tumours can develop.

16 How are cancer cells different from normal cells in the lung tissue?

17 Why do cancer cells in an organ make the organ less efficient?

18 Why might the growth of cancer tumours in an organ have fatal results?

◆ SUMMARY ◆

- The respiratory system can be divided into three parts: the air passages and tubes, the pump and the respiratory surface (*see page 55*).
- Breathing is the movement of air in and out of the lungs (*see page 55*).
- The breathing movements, inspiration and expiration, are caused by the movement of the chest wall and the diaphragm (*see page 58*).
- Gaseous exchange takes place between the alveoli and the capillaries next to them (*see page 59*).
- Respiration is the process by which oxygen is taken into the body, transported to the cells and used in a reaction with glucose to release energy (*see page 60*).
- The word equation for aerobic respiration is:

  glucose + oxygen → carbon dioxide + water (*see page 61*).
- Smoking damages the bronchi and alveoli and can cause bronchitis, emphysema and cancer (*see pages 61–62*).

End of chapter questions

1 Describe the processes and structures involved in moving oxygen molecules from outside the nose to inside the blood in the lung.

2 A survey was made to find out about the smoking habits of young people aged 11–14. For each year group a thousand boys and a thousand girls were asked if they were occasional smokers or regular smokers.

Smokers	11 years	12 years	13 years	14 years
boys, occasional smokers	20	40	70	80
boys, regular smokers	10	30	60	140
girls, occasional smokers	15	0	90	110
girls, regular smokers	10	35	70	160

a) How is the data for occasional and regular smokers for boys similar?
b) Where is there an anomalous result? Give an explanation for it.
c) What is the difference in the number of regular smokers between boys and girls at the age of 14?
d) What percentage of the boys aged 12 are regular smokers?
e) Do you predict the percentage of boys and girls who are regular smokers will go up, stay the same or go down for boys and girls aged 15?
f) Which group, boys or girls, do you think will have the larger percentage of occasional smokers at the age of 15?

6 Reproduction in humans

- The changes in the body from birth to adult
- Changes in behaviour in adolescence
- The reproductive organs
- The menstrual cycle
- How a human egg is fertilised
- The development of a baby
- Birth
- Early life

How do people change as they grow from a baby to an adult? What is the structure of the male and female reproductive organs? How is a human egg fertilised and how does it grow into a baby? These questions will be answered in this chapter.

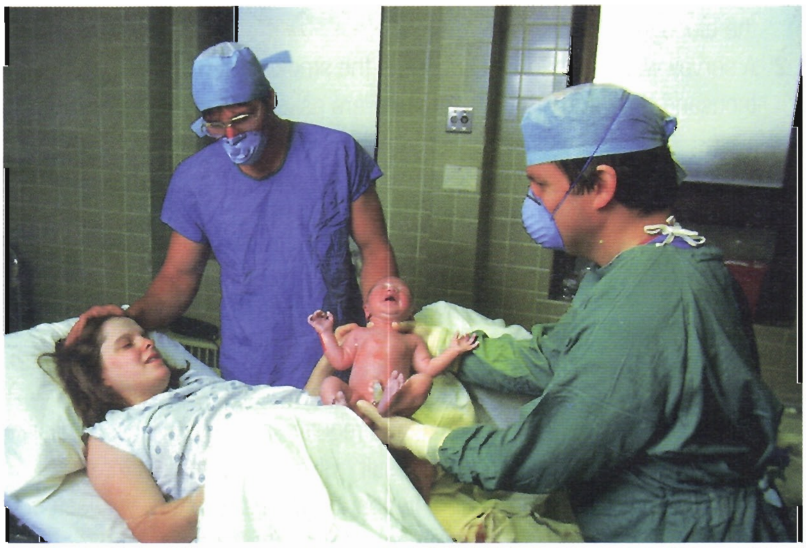


Figure 6.1 This new human was born only seconds ago.

How the changes begin

The bodies of newborn male and female babies are very similar. The sex of a baby can only be declared after looking at the baby's genitalia – the external parts of the reproductive organs. For the next ten years the bodies of boys and girls continue to be very similar (except for the genitalia), then changes begin.

Behind the nose and beneath the brain is an organ called the pituitary gland. This is one of several glands that secrete different **hormones** into the blood. A hormone is a chemical that is produced in one part of the body, circulates all round the body in the blood but only has an effect on a specific part of the body. At around the age of 10 to 13 in girls and 12 to 14 in boys, the pituitary gland secretes increased amounts of two hormones, one called **growth hormone** and the other called **gonadotrophin**.

Growth hormone travels around the body and stimulates growth in the hands and feet, then the hips and chest, and then causes the trunk followed by the legs to increase in length. These changes in body size can make people feel uncomfortable.

Gonadotrophin stimulates the production of sex hormones. In females the sex hormones are produced in the **ovaries**. They produce two sex hormones, **oestrogen** and **progesterone**, in large amounts. In males the sex hormones are produced in the **testes** or testicles. They produce **testosterone**. The sex hormones cause the reproductive organs to develop fully and cause the development of body features known as secondary sexual characteristics. The sex hormones work with the growth hormone. In females they cause the hips to grow wider than the shoulders and to develop fat around them to give a smoother shape. In males testosterone causes the shoulders to grow wider and heavier than the hips.

Table 6.1 Secondary sexual characteristics

Males	Females
growth of hair on the face, the armpits and the pubic region	growth of hair in the armpits and the pubic region
voice becomes deeper	breasts develop
growth of penis and testicles	growth of vagina and uterus
	pelvis widens

Table 6.1 shows the secondary sexual characteristics that develop in males and females due to the action of these sex hormones. These changes take place over a period of about three years in girls but may take longer in boys. There is a great variation in the time at which the changes begin and also in the nature and the size of the changes. These variations can make people unnecessarily anxious and cause them to worry if they feel they are not

1 How may the body of a girl and a boy change from the beginning to the end of puberty?
2 Why do some people feel anxious as they go through puberty?

changing in the correct way. When the changes are complete each person is capable of reproduction. This period of change is called **puberty**. It takes place in the first half of **adolescence**, which is the time when a person changes from a child to an adult. In adolescence, in addition to becoming sexually mature, a person also develops adult emotions and social skills.

Figure 6.2 Most of the people in this school hall are going through puberty, while the rest went through puberty many years ago.

All mixed up

The greatest physical and emotional changes in a person's life take place during adolescence. At the end of this time people become adults, usually with a wider range of social skills to allow them to live independently, if they wish, and to develop their own ambitions for a happy life.

During adolescence people have to learn to cope with both the physical and emotional changes at once. In addition to the physical changes, girls have to learn to cope with periods (see page 68) and boys may have 'wet dreams' in which they release semen (see page 70) when they are asleep. A person's main emotional change is in wanting to be more independent and to have more control over their life. Generally, other members of the family adjust to these changes and the adolescent is allowed more freedom of choice in clothes and use of free time. Many schools also provide a wide range of sports, clubs and activities to help the adolescent to develop emotionally and socially.

It is natural for people in adolescence to be anxious sometimes and to worry whether they are going through

the proper physical change. Some also try to be too independent too quickly. This may lead to arguments with parents and other adults. As well as seeking independence from their families they are also anxious not to lose their friends and may feel under pressure to follow the way their friends behave, even though they would prefer to do something else. The sex hormones also influence thoughts and make people interested in the opposite sex. The degree to which the sex hormones do this varies as much as the physical changes they make. All the changes taking place over a few short years can make many adolescents feel confused. This is natural. Some people find that talking to others helps them cope, while other people feel embarrassed to talk about how they feel.

For discussion

Do you think this is a fair description of how people think and feel during adolescence?

What would you add to this and what do you not agree with?

Figure 6.3 Playing instruments together is a great way for people to learn about each other and develop teamwork and social skills.

The male reproductive organs

The testicles develop inside the body of the unborn child and usually move down to the outside of the body before the baby is born. The testicles are held in a bag of muscle and skin called the scrotum. They are positioned outside the body because the conditions are cooler there and are more favourable to sperm production. Each testicle contains long microscopic pipes called seminiferous tubules. The male **gametes** or sex cells are made inside these tubes. They are the sperm cells. On the top and side of each testicle is an epididymis. This is a long, coiled tube in which the sperm cells collect. The sperm cells travel to the outside of the body along the sperm duct and the urethra. There are glands along the path to the outside that add liquid to the sperm cells. The mixture of liquid is known as seminal fluid, or semen.

The urethra runs through the middle of the penis. It is also connected to the bladder and is the tube through which urine flows. Semen and urine do not flow down the urethra at the same time.

The penis contains spongy tissue along its length that can fill with blood to make it hard, stiff and erect (see page 70). The tip of the penis, called the glans penis, has a large number of receptors and is very sensitive. The glans is covered with a fold of skin called the foreskin. If circumcision has taken place the foreskin will have been removed.

The female reproductive organs

The ovaries develop inside the body and, unlike the testicles, they stay there because egg production can take place at body temperature. Each ovary contains about 200 000 potential egg cells. Egg cells are the female gametes. Eggs are released as part of the **menstrual cycle** (see below). When an egg is released from an ovary it passes into the trumpet-shaped opening of the oviduct – a tube that connects to the uterus or womb. If an egg is fertilised (see page 71) it develops into a foetus in the uterus.

The uterus is connected to the vagina by the cervix. The vagina opens to the outside next to the opening of the urethra. Both openings are protected by folds of skin called labia. These folds also protect a region about the size of a small pea called the clitoris. This region has a large number of receptors like the tip of the penis.

3 How are the male and female reproductive organs different?
4 How are they similar?

The menstrual cycle

From the beginning of puberty the menstrual cycle occurs approximately every month in females. It does not take place when the female is pregnant. It includes a period of bleeding from the vagina which may last for about four days. During this time an egg starts to mature in one of the ovaries. About ten days after a period of bleeding ends, the egg, which is about the size of the dot on this i, is released from the ovary. Alternate ovaries release an egg each month. The egg is then moved down the fluid-filled oviduct by the movement of cilia in the oviduct walls.

At the same time as the egg is maturing in the ovary the uterus wall is thickening with blood. It does this to prepare to receive a newly formed **embryo** in case fertilisation takes place. The egg may survive for up to two days in the oviduct and fertilisation can take place during this time. If the egg is not fertilised no further development of the egg takes place. About 12 days after the egg dies, the uterus wall breaks down and blood passes out of the vagina. Another menstrual period begins.

The length of time of the period of bleeding varies between girls and so does the amount of blood that is released. Some girls and women feel ill a day or two before their period starts or feel pain for the first few days, while others are not affected in this way.

The menstrual cycle continues until the beginning of the **menopause**, which may start at about the age of 45. During the menopause periods may become irregular and eventually stop. The menopause may end when a woman is in her early 50s.

5 How long is the average menstrual cycle?
6 How does the wall of the uterus change during the course of the cycle and why?
7 What is the cause of the menstrual bleeding?
8 In what ways can periods vary?

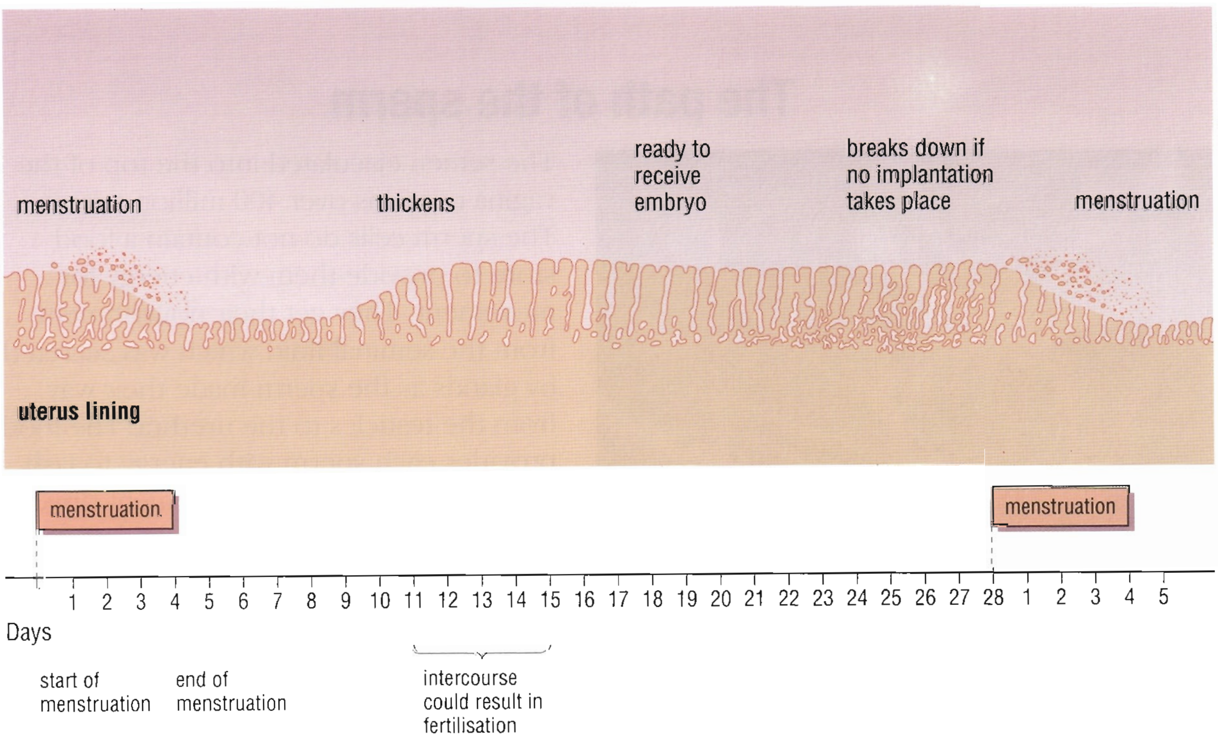


Figure 6.4 The menstrual cycle

Sexual intercourse

Before sexual intercourse can take place the penis must become erect. This happens by the action of a muscle at the base of the penis. The blood collects in the spongy tissue and makes it expand and become hard.

Prior to intercourse the vagina may also widen to ease the passage of the penis into it. The lining of the vagina may secrete fluid that acts as a lubricant and further helps the penis to enter the vagina.

When the penis is inside the vagina both the male and female may make thrusting movements to stimulate the sensitive areas of the penis tip and the clitoris. This may give each partner a feeling of pleasure called an orgasm. When the male has an orgasm it is accompanied by a contraction of the muscles in the epididymis and sperm ducts which propels the semen through the penis into the vagina. The action of releasing semen is called an ejaculation. The volume of semen ejaculated is usually about 3–5 cm^3.

The path of the sperm

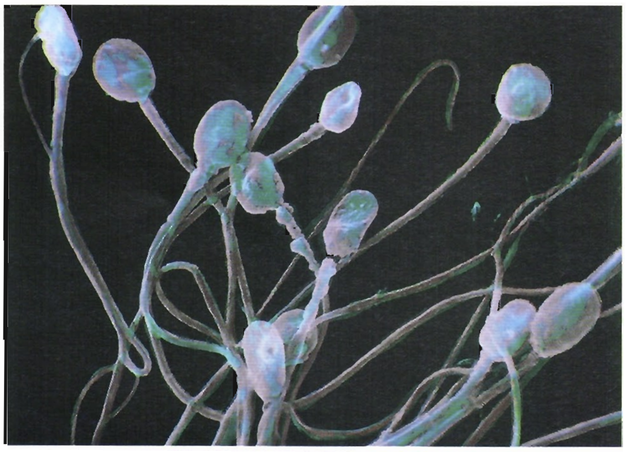


Figure 6.5 Photomicrograph of sperm cells

The semen ejaculated into the top of the vagina contains over 400 million sperm. The sperm cells do not contain a food store to provide them with energy for movement. They get their nourishment from the seminal fluid which was secreted by glands as the sperm made their way from the testicles to the urethra. The food provides each sperm with energy to lash its tail like a whip. This movement drives the sperm forwards.

The sperm travel through the cervix and up the mucus lining of the uterus wall into the oviducts. It takes them about 4–6 hours to make their journey. Millions die on the way leaving only a few thousand to enter the oviduct. As the sperm swim along the oviduct even more die so that only a few hundred reach their destination. The sperm may survive for two or three days here before they die. During this time, if the sperm meet an egg, fertilisation may occur.

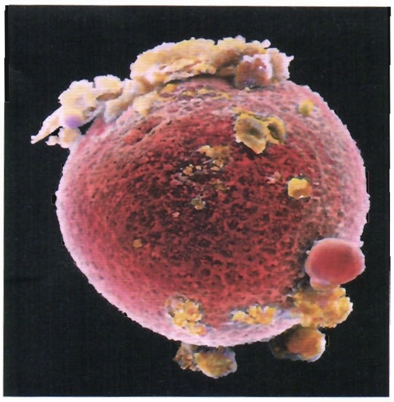


Figure 6.6 Photomicrograph of an egg

9 Compare the ways in which the sperm and egg move along the oviduct.

How the egg is moved

The egg is much larger than a sperm cell because it contains its own food store. This is to provide energy and materials for the very early development of the embryo if the egg is fertilised. Unlike the sperm, the egg has no means of propulsion. It is moved by the action of the cilia in the wall of the oviduct. They wave backwards and forwards and push the egg along.

Fertilisation

When the sperm cells meet an egg in the oviduct they crowd around it. The head of only one sperm cell penetrates the cell membrane of the egg (see Figure 6.7). This sperm cell's head breaks off from the tail and moves through the egg cell's cytoplasm to the nucleus. When the head reaches the egg cell's nucleus fertilisation takes place. In this process the nucleus inside the sperm head fuses with the egg cell nucleus. The fertilised egg is called a **zygote**. Changes to the cell membrane around the zygote prevent other sperm heads from entering and fusing with the nucleus. The nuclei of the sperm and the egg contain instructions for the development of the baby.

If the fertilised egg or zygote becomes implanted into the uterus wall, it can develop into a baby. The period of time from fertilisation (which is also known as conception) to the birth of the baby is known as pregnancy.

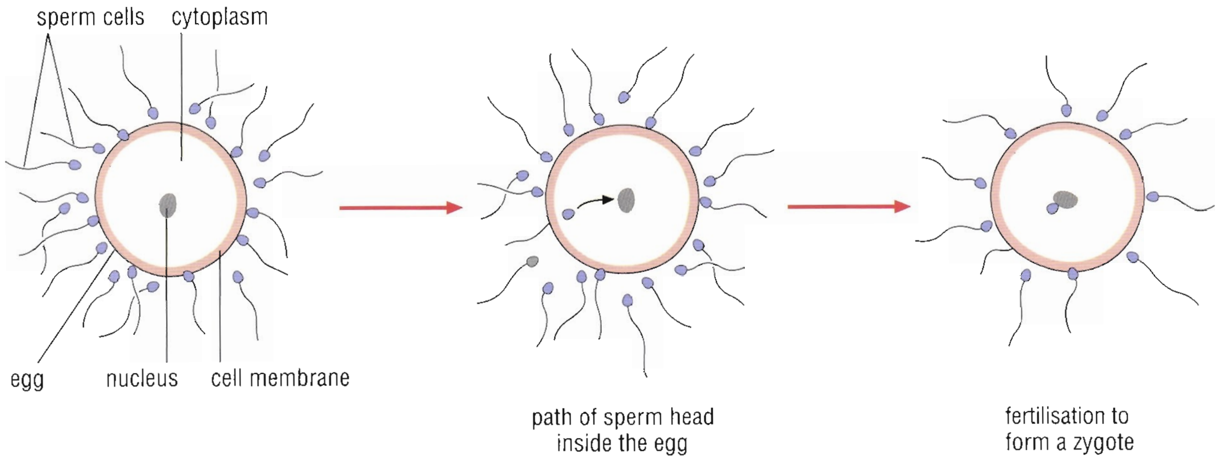


Figure 6.7 Fertilisation

The development of the baby

After fertilisation the zygote divides into two cells, then four, then eight and so on (see Figure 6.8). The zygote does not increase in size in the first seven days, so cells become smaller at each division. By seven days after fertilisation the cells have formed a hollow ball and have reached the uterus. The hollow ball sinks into the thick lining of the uterus wall, which has a large amount of blood passing through it. This process of sinking into the uterus wall is called **implantation**.

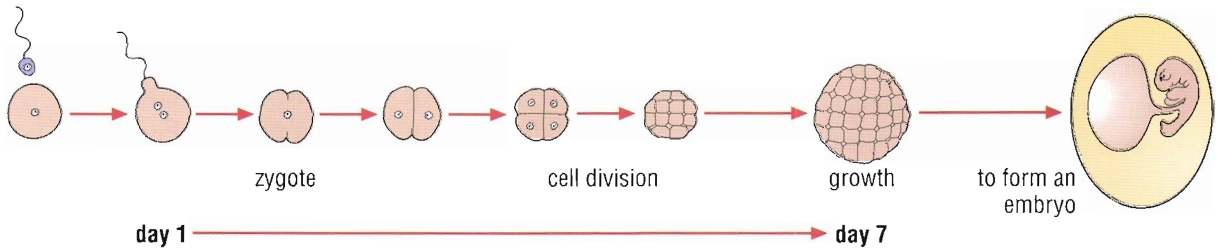


Figure 6.8 The early development of the zygote into an embryo

The placenta

The cells on the surface of the hollow ball of cells of the zygote will form the placenta. This takes in food and oxygen from the mother's blood so that the cells can grow and divide. Waste products, such as carbon dioxide from the cells' activities, pass across the placenta to the mother's blood so she can remove them through her own lungs or kidneys.

During the course of the pregnancy the placenta grows into a disc with a diameter of about 20 cm. It forms microscopic finger-like projections called villi that penetrate into the uterus wall and make a very large surface area for the exchange of materials between the mother and her baby. The placenta is attached to the developing baby by the umbilical cord. Blood runs through vessels in this cord between the placenta and the baby's tissues. The baby's blood and the mother's blood always remain separate. The mother's blood is at a much higher pressure than the baby's blood so it would damage the baby's blood vessels if it passed directly through the placenta. Also, the two kinds of blood may not be compatible. This means that if they mixed, clotting would occur which would block the blood vessels and lead to further damage.

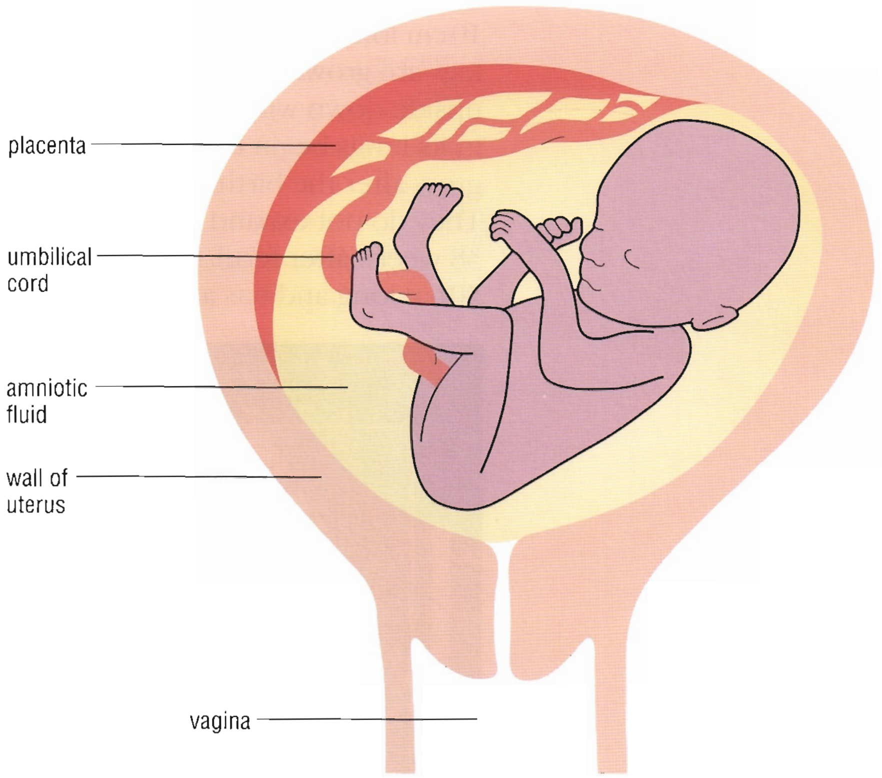


Figure 6.9 The foetus in the uterus

The placenta makes hormones that stop the ovaries producing any more eggs and which stop the uterus wall from breaking down as it would normally do in the menstrual cycle. Antibodies pass from the mother's blood through the placenta to her baby to give protection from diseases.

Embryo and foetus

Although most people refer to a baby growing in the uterus, the words embryo and **foetus** are often used for the early stages. While some of the cells inside the hollow ball join with those on the outside to make the placenta, most of the cells form the embryo. At the end of the first two weeks of development the embryo is a flat disc of tissue but by four weeks it has developed a simple body shape with stumps where the limbs will grow. Internally its heart has started to beat. By eight weeks all of the organ systems have formed and the embryo, which is now 2.5 cm long, is called a foetus.

The foetus continues to increase in size and the organ systems become more fully developed. By 14 weeks the sex of the foetus can be revealed by an ultrasound scan and at about 16 weeks the foetus makes movements that

the mother can feel. The foetus at this time is only about 10 cm long. By 20 weeks the foetus is 12.5 cm long but its legs are growing quickly. Eight weeks later the foetus turns upside down with its head towards the cervix. The alveoli in its lungs begin to grow at this stage and continue to grow after the birth. Before birth the lungs contain a fluid. They do not expand until just after the baby is born. By 38 weeks after fertilisation of the egg the foetus is about 50 cm long and has a mass of about 3 kg.

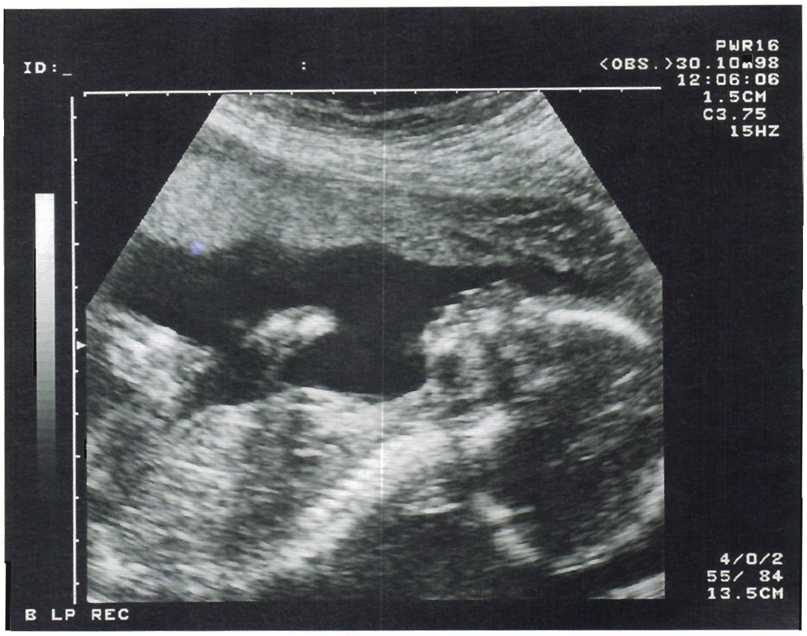


Figure 6.10 An ultrasound picture can be used to check the development of the foetus.

The baby is now ready to be born. The length of time between fertilisation and birth is called the **gestation period**. In medicine this is referred to as 40 weeks (rather than 38 weeks) because the time is calculated from the first day of the last menstrual period.

The amnion and its fluid

During the development of the foetus a bag forms around it called the **amnion**. This contains watery fluid. The fluid acts like a cushion around the foetus and protects it from pressures outside the uterus that might squash it. The mother, for example, may be accidentally pushed against in a crowded street. The fluid also allows the foetus to float freely so that the growing limbs have space to develop and are not pressed against the wall of the uterus where the growth would be restricted.

10 How do the placenta and the amniotic fluid help the embryo and foetus develop?

11 How is an embryo different from a foetus?

Birth

There are three stages to the birth process. In the first stage the muscles in the uterus wall begin to contract. The time between each contraction may be up to 30 minutes at first. During 12 to 14 hours of this first stage the time between contractions shortens to 2 to 3 minutes. At some point the contractions cause the amnion to break and the fluid to pass out down the vagina. This is called the 'breaking of the waters'. At the end of the first stage the cervix has widened so that the head of the foetus can start to pass down it.

In the second stage the mother contracts her abdominal muscles with the contractions of the uterus to push the foetus down the birth canal. This stage may only last a few minutes and is completed when the baby has been born and the umbilical cord has been cut and clamped to prevent loss of blood. If there are twins the contractions stop for about 10 minutes after the first baby has been born and then start again. Only a few contractions may be needed for the second baby to be born.

The two stages from the first contractions of the uterus to the birth of the baby are called labour.

The third stage lasts for about 20 minutes after the second. During this time the placenta comes away from the wall of the uterus and passes down the vagina. When it has left the mother the placenta is called the afterbirth.

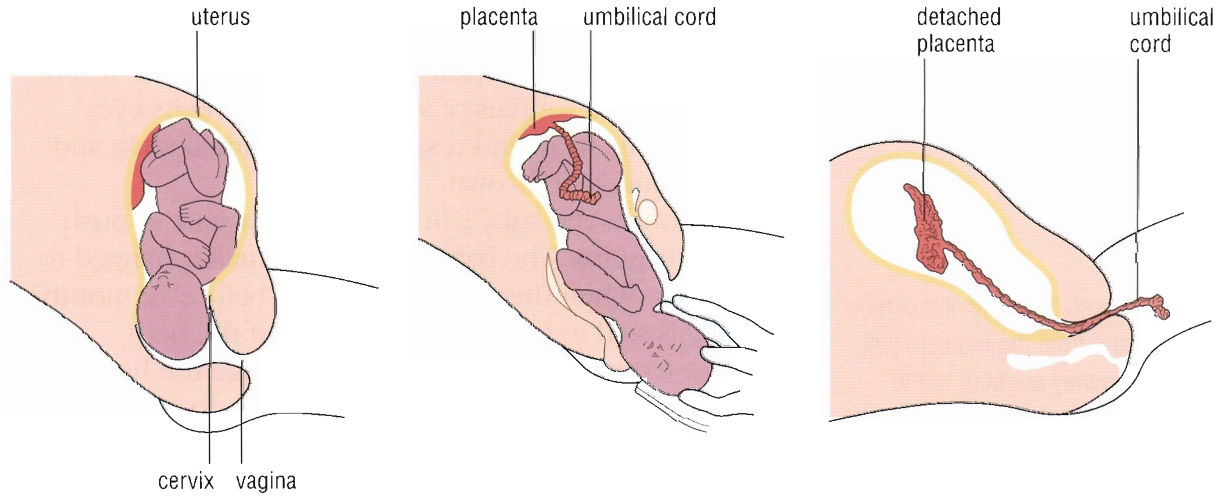


Figure 6.11 Diagrammatic representation of birth

Twins

About one in a hundred pregnancies produces twins. The twins may be identical or non-identical. Identical twins form from the same fertilised egg. At the first cell division of the zygote the two cells move apart and each one develops into an embryo. Non-identical twins form from two eggs which were released into the oviduct at the same time. Each egg is fertilised by a different sperm. Identical twins share the same genetic material but non-identical twins have different genetic material.

12 A boy and girl are a pair of twins. Are they identical or non-identical? Explain your answer.

Early life

The baby starts to suck as soon as it is born. During pregnancy some of the hormones produced by the mother cause the milk-secreting or mammary glands in her breasts to develop. The milk that the mother provides for her baby contains all the nutrients the baby needs. It also contains antibodies to protect the baby from disease. Some mothers cannot provide enough milk for their babies and use special powdered milk made up into a liquid instead. This is delivered in a sterile bottle with a teat.

The end of the umbilical cord attached to the baby withers away and falls off, leaving the navel.

The baby continues to grow rapidly and the organ systems become more coordinated. At the end of the first month the baby can hold its head up for a few seconds. In the following months the baby can lift its head more steadily, kick and push itself up on its hands. It will listen and look for the sources of sounds by moving its eyes and turning its head and respond by making cooing and gurgling sounds of its own.

By 6 months the baby's first set of teeth start to push through its gums. The baby's diet is gradually changed to solid foods. When this happens, usually before 12 months, the baby is said to be weaned. All parts of the body continue to grow but at about 4 years of age the head has reached almost its full size. The sex organs do not develop fully until puberty.

13 How does the body of a person change from the moment just before they are born to the time just before puberty?

Figure 6.12 Young children need a stimulating environment in which to grow up.

SUMMARY

- The changes in the human body at puberty are brought about by the sex hormones (*see page 65*).
- The male and female reproductive organs have differences and similarities (*see pages 67–68*).
- The menstrual cycle occurs due to the monthly release of an egg (*see page 68*).
- Fertilisation is the fusion of a sperm nucleus with an egg nucleus (*see page 71*).
- The development of the embryo takes place in the uterus (*see page 72*).
- The placenta and the amnion play important parts in the development of the embryo and foetus (*see pages 72–74*).
- The uterus and abdominal muscles are used in the birth process (*see page 75*).
- Many changes take place in the body in a child's early life (*see page 76*).

End of chapter questions

1 How does a knowledge of the basic facts of reproduction help someone going through puberty?

2 Gila and Barry have got a record of their heights (in centimetres), measured once a year from birth until they were 17 years old.
Gila's record is: 51, 75, 87, 95, 102, 108, 115, 122, 127, 132, 138, 144, 151, 157, 159, 161, 162, 163
Barry's record is: 51, 76, 88, 96, 103, 109, 117, 123, 129, 135, 139, 143, 149, 154, 160, 167, 173, 174

a) Make a table of the results.
b) Plot each set of results on the same graph.
c) At what ages were Gila and Barry the same height?
d) Who grew more quickly between the ages of:
i) 8 and 9
ii) 11 and 13
iii) 14 and 17?

7 Diet, drugs and disease

- Diet, drugs and disease
- How diet affects conception and pregnancy, growth and development, behaviour and health
- How drugs affects conception and pregnancy, growth and development, behaviour and health
- How disease affects conception and pregnancy, growth and development, behaviour and health

There are three threats to a healthy life. They are an unhealthy diet, taking drugs for non-medicinal purposes and the attack of disease. In this chapter we will look at how each of these threats affects certain aspects of human life. These aspects are conception and pregnancy, growth and development, behaviour and health. In the following pages we look at what these threats can do but we also look briefly at what can be done to make things better.

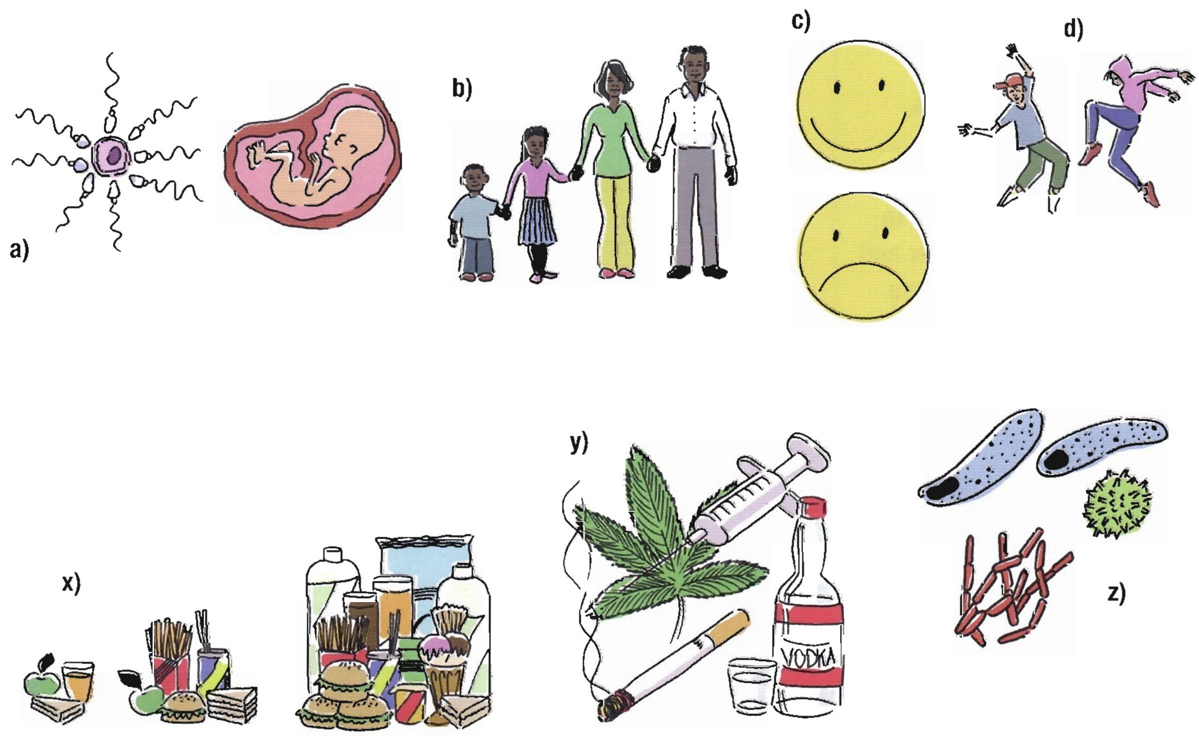
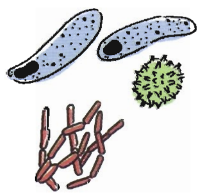


Figure 7.1 The symbols used in this chapter to help you think about the information are: **a)** conception and pregnancy, **b)** growth, **c)** behaviour, **d)** health, **x)** diet, **y)** drugs and **z)** disease.



Diet, drugs and disease

The diet is the food that a person normally eats on a regular basis throughout the year. It may be a balanced diet which is healthy, or an unbalanced diet which is unhealthy (see pages 29–33).

A simple definition of a drug is a substance that, when taken into the body, alters the way the body works. There are three main types of drug: drugs used in medicine, non-medicinal drugs and performance-enhancing drugs.

Medicinal drugs are used to prevent, treat and cure disease and to ease pain. Non-medicinal drugs affect the nervous system and bring about changes in the way the brain works which may alter a person's behaviour. These drugs are illegal in many countries. Performance-enhancing drugs are used by some people who take part in sport to increase muscle growth or make their senses more alert. In addition there are two other substances which are in common use in many parts of the world but that can be considered as drugs too. They are alcohol (in alcoholic drinks) and nicotine (in tobacco products such as cigarettes).

A disease is an abnormal condition which affects the health of the body and prevents it from working properly. The body can recover from many diseases with treatment but if the treatment fails the disease can be fatal.

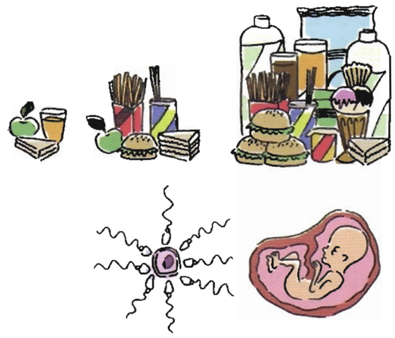
Table 7.1 gives some types of diseases with examples.

Table 7.1

Type of disease	Examples
hereditary disease	cystic fibrosis, haemophilia
nutritional disease	beriberi, scurvy, rickets (see page 27)
degenerative disease	heart attacks and strokes (see page 52)
transmissible disease	malaria, tuberculosis and AIDS (see page 89–90)

For discussion

When a disaster happens, such as an earthquake, volcanic eruption, flood or tsunami, survivors gather in refugee camps for shelter and food. What types of disease can develop quickly in these conditions? Explain your answer.



Diet

Conception and development in the womb

The best chance for large numbers of sperm cells being produced in males and a regular menstrual cycle in females is for people to eat a balanced diet (see page 32). In places where poverty prevents people from having a balanced diet the lack of the full range of nutrients can reduce sperm production and stop the menstrual cycle.

If conception does occur the poor diet of the mother also slows the growth of the foetus and when the baby is born it is smaller than normal and less able to resist the attack of diseases.

In places where there is greater choice of food for the mother, soft cheeses such as Camembert should not be eaten as they can contain microorganisms that cause listeria which can be fatal to the foetus. Also, caffeine, a substance in coffee, chocolate and tea must be consumed in smaller amounts than usual as it can slow down the growth of the foetus in pregnancy.

Figure 7.2 This mother has not had a balanced diet and so her baby is small.

Growth and development in young people

If there is simply not enough food, as happens in areas suffering from a famine, the growth and development of young people is severely affected. If there is just enough food for the young people to survive, their bodies will grow and develop much more slowly than normal and as time goes on their bodies will be smaller and less well developed than people on healthy diets. If their diet returns to normal they can recover and develop normally again.

When the diet of a child under one year old lacks protein and energy, a condition called marasmus develops in which all the energy stores in the body are used up. This results in the disappearance of body fat and the muscles wasting away. This condition is fatal if it is not treated.

Kwashiorkor is a condition which develops in children over eighteen months old in places where there is a poor diet (see Figure 7.3). It develops in the following way. A mother feeds her baby breast milk but when she has a second baby the first child is given starchy food such as yam or cassava which has little protein in it. This results in poor development of the muscles and the swelling of the part of the body below the chest in the first child.

1 Kwashiorkor is a Ghanaian word for 'the sickness a baby gets when a new baby arrives'. Why is this an accurate description?
2 Look at Figure 7.3 on page 82. Why might people think that a child suffering from kwashiorkor is well fed?

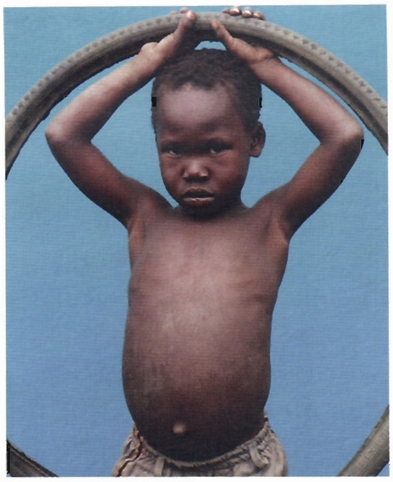


Figure 7.3 This child is suffering from kwashiorkor which is a result of a diet with too little protein.

3 How do obese people put their health and lives at risk?

Figure 7.4 This child is obese which is a result of a diet with too much energy content.

Obesity is a condition which develops in children (and adults) who have a very high energy diet. The diet may be made up of lots of sweets, chocolates, crisps, pizzas and other foods with a high carbohydrate and fat content. The energy is stored in the body as fat and the increased body mass makes the person tend to move around less than normal.

As the person uses less energy than before but keeps eating the high energy diet, even more body fat is produced. This can affect the working of the heart (see pages 50 and 52) and the increase in body mass puts extra strain on the bones and the joints. Obesity can lead to a form of diabetes called type 2 diabetes. This affects the way that the body controls the amount of digested sugar in the blood. Normally the body produces a substance called insulin which helps the body to take extra sugar out of the blood and store it in the liver. In type 2 diabetes the body no longer responds to the insulin and blood with a high sugar content flows around the body. This can eventually cause blindness and damage to the nerves and blood vessels in the feet which can only be treated by amputation. It can also cause kidney damage which can be fatal.

Behaviour

People who lack food may feel tired and have little energy to move around. People who suffer from obesity may also suffer from low self confidence, feel depressed and be unable to sleep well.

Behaviour can also be affected by particular substances that are eaten. There is a childhood condition called hyperactivity which some scientists believe is due to the children eating foods and taking drinks which contain certain additives. The additives are sunset yellow, quinoline yellow, carmoisine, allura red, tartrazine and ponceau.

Effect on general health

People can stay healthy by eating a balanced diet (see page 32). If a nutrient is missing from the diet then a deficiency disease may develop (see pages 26–28). If people eat a diet rich in foods which contain fat they may lay down cholesterol in their blood vessels (see page 52).

Treating malnutrition and starvation

In areas of famine, aid workers give malnourished children powdered milk mixed with water. There are two forms of powdered milk called F75 and F100. Children are

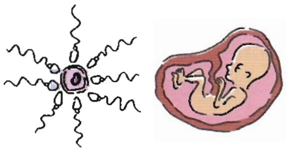
4 a) Look at Table 2.2 on page 30 and compare the nutrients in rice and peanuts.
b) How do you think a food based on peanuts is better than one based on rice to help people recovering from starvation and malnutrition?

first given F75 which prepares their body to start digesting food again. Then, after a few days, they are fed F100. This contains more proteins and energy to help the body begin to build up again. The children may also be given an alternative to F100 called Plumpynut which is made from peanut paste, powdered milk, minerals, oil, sugar and vitamins. A second food called Unimix is also added to the diet. This is a flour made from maize and soya beans to which powdered milk, minerals, oil, sugar and vitamins are added. It is mixed with water to make a porridge. The children may be fed on this diet for up to a month as their bodies recover and they can then move on to other foods.

Figure 7.5 Children receiving food aid at a distribution centre in Somalia

Treating obesity

As obesity develops due to an unbalanced diet, one part of the treatment is to help the sufferer change to a balanced diet. The second part is to build up an exercise programme so more energy is used up and the body is strengthened. In the treatment of obese adults the aim is to lose body mass but the treatment of obese children is slightly different. This is because children are still growing. The aim in the treatment of obese children is to help their bodies grow into the correct proportions so that over a few years the child's body mass and appearance becomes normal.



Drugs

Conception and development in the womb

Drinking alcohol, smoking cigarettes and using non-medicinal drugs all affect conception. Alcohol reduces the number of sperm produced in males. Smoking can make the ovaries work less efficiently. Both these effects reduce the chance of conception. Cannabis, cocaine, heroin and ecstasy can make the menstrual cycle (see page 68) become irregular or even stop. They can slow down sperm production and cause some sperms to develop abnormally.

Figure 7.6 This abnormal sperm has two tails

If someone uses drugs when she is pregnant it can affect the foetus.

Table 7.2 *The effects of drug use in pregnancy*

Drug	Effect on foetus
alcohol	• drinking even small amounts can cause nerve damage • drinking large amounts can cause the head to be smaller and cause abnormal development of the eyes, nose and lips • foetal alcohol syndrome
tobacco	• slows down growth – the organs may be smaller than normal, the lungs may work less efficiently
non-medicinal drugs	• slows down growth • makes it less able to fight disease • the baby can become dependent on the drug the mother was taking

5 Why do drinking alcohol and smoking reduce the chance of conception?

6 How does the use of non-medicinal drugs affect conception? Explain your answer.

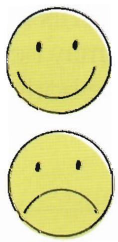
7 How is the sperm in Figure 7.6 abnormal? Look at Figure 6.5 on page 70 to help you answer.

Growth and development in young people

In certain parts of the world children take up sniffing solvents such as those used in glues. The reason for this is that the solvents are easier and cheaper to get than drugs. The solvents can cause a loss of appetite which results in a loss of body mass. They can cause headaches, sickness, coughing and harm to the brain that results in loss of memory. The solvents harm the lungs, affect how the nerves control breathing and damage the structure of the liver, kidneys and bone marrow. After sniffing the solvent a person loses control of themselves and may suffocate on the plastic bag from which they inhaled the solvent. They may also become unconscious and if they are sick their vomit may block their windpipe causing death by suffocation.

8 Describe how a person's body changes as they take up glue sniffing until it kills them.

Figure 7.7 Sniffing solvents can cause the user to become unconscious



Behaviour

Alcohol affects the nervous system and slows down the speed at which nerve cells carry signals. A small amount of alcohol may make a person feel more relaxed but it also makes the nerves work slightly more slowly. This makes the person react more slowly. As the person drinks more alcohol their reactions slow down even more and their behaviour may change. Their voice may become louder and they may become reckless and even aggressive. The person may find it more difficult to think and speak clearly. If they continue to drink more alcohol their movements may become uncoordinated and they may be unable to walk. They may then fall asleep or become unconscious. In extreme cases they may be sick while unconscious and it may block their windpipe causing death by suffocation.

9 People who have been drinking alcohol should not drive. Why?

People begin taking non-medicinal drugs for a variety reasons. Drug abuse can often start in the teenage years and sometimes even earlier. People may take non-medicinal drugs because their friends are trying them and they find it

difficult to say no because, if they do, their friends may no longer like them. They may also take them because they think that it is exciting to use substances that are illegal.

Older people may take non-medicinal drugs because they are unhappy, lonely or feel that they are unable to cope with life. Whatever the reason, taking non-medicinal drugs can be harmful. They affect the nervous system and if they are used over a long period time they can cause damage which results in memory loss, hallucinations and mental illness.

If a person continues to take drugs over a long time, for example through their teenage years, their body becomes more tolerant to the drug and larger amounts are needed for the person to feel its effects. The drug taker's brain becomes so used to the drug that the drug taker becomes dependent on it. This is known as addiction. If a person who has been taking a drug for a while suddenly stops they may suffer withdrawal symptoms. They may also become upset because they fear that they cannot cope with life without the drug.

Effect on general health

The effect of smoking on health is described on page 61.

Alcohol affects health because it is a poison. The liver collects poisons from the blood as it flows through and breaks them down to make them harmless. If large amounts of alcohol are drunk over many years the liver may become inflamed and develop a disease called hepatitis. Parts of the liver may turn to scar tissue. This can lead to the cirrhosis of the liver. This reduces the liver's ability to deal with poisons and may be fatal.

Non-medicinal drugs affect the body in a variety of ways as summarised in Table 7.3.

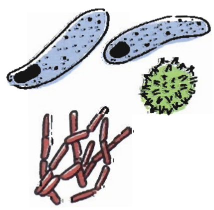
Table 7.3 Non-medicinal drugs – how they are used and their effects

Non-medicinal drug	How it is used	Effects
cannabis (marijuana)	smoked	• hallucinations, mental illness
cocaine and crack	sniffed (called snorting), smoked or injected	• overconfidence and carelessness, sickness, sleeplessness, mental illness
heroin	smoked or injected	• can slow down body reactions to the point of death • needle users may catch hepatitis and AIDS if they share needles
ecstasy	swallowed in tablet form	• speeds up body reactions, produces confusion, can be fatal
amphetamines	swallowed in tablet form or sniffed (snorted) in powder form	• increases activity at first, then produces feelings of sadness which may last for up to two days • can cause heart and brain damage
LSD	swallowed in tablet or liquid form or even as a small piece of paper	• hallucinations, which can be terrifying and to which the brain may 'flashback' weeks or months later

For discussion

How do you think the poster image in Figure 7.8 conveys the unpleasant consequences of taking drugs? What would you put on a poster to try to stop people from taking non-medicinal drugs?

Figure 7.8 Posters using images like this are used to show how using non-medicinal drugs can affect lives. They aim to prevent people from starting to take non-medicinal drugs.



10 How are HIV and AIDS linked?

Treating and preventing drug abuse

All addictions to drugs can be treated. Smokers can receive advice and support from health services. They may suck nicotine gum or attach patches containing nicotine to their skin so they still receive some nicotine while not smoking. This reduces the effect of the withdrawal symptoms and helps them break the habit of lighting up a cigarette.

People who have become addicted to alcohol can also receive advice and support from health services. There are many options to help them give up drinking alcohol. These include taking medicines, joining groups of others who have given up drinking alcohol and staying in a rehabilitation centre where there is medical supervision, a course of activities to improve health and no access to alcoholic drinks.

People who are addicted to non-medicinal drugs may also attend rehabilitation centres but can also get support from health services to break their drug-taking habit.

Disease

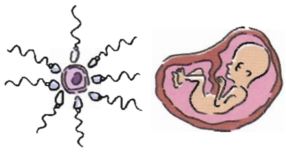
There are many diseases which affect human life. In this section we shall look briefly at just a few of them, mainly sexually transmitted diseases (STDs), malaria, AIDS and tuberculosis (TB).

Sexually transmitted diseases are known by the initials STDs but they may also be called sexually transmitted infections and known by the initials STIs. They are transmitted by sexual intercourse (see page 70) and examples of these diseases are chlamydia, gonorrhea and syphilis.

Malaria is a disease which is caused by a microorganism belonging to the Protoctista kingdom which includes amoeba. The disease is spread by the female of certain species of mosquito belonging to the species group or genus called *Anopheles*.

AIDS stands for Acquired Immune Deficiency Syndrome which is a disease of the body's immune system. It is caused by a virus named the human immunodeficiency virus which is commonly called HIV. The immune system fights disease-causing organisms and viruses. When it is damaged all types of other diseases can then attack the body. It is spread mainly by sexual intercourse with an infected person or by drug users sharing unsterilised needles.

Tuberculosis is a disease caused by a microorganism belonging to the bacteria group. It is spread by droplets produced by coughing, sneezing and spitting and infects the lungs. It can then spread to the brain, kidneys and bones.



Conception and development in the womb

Worldwide, the most common disease preventing conception in females is called Pelvic Inflammatory Disease (PID). It can be caused by a wide range of infections and affects the ovaries, fallopian tubes and the uterus. When the fallopian tubes are infected they become inflamed and are the main cause of infertility. The main causes of PID are sexually transmitted diseases (STDs). Infertility in both men and women can also have other causes, such as diabetes and kidney disease.

When males are infected with a disease, particularly a sexually transmitted disease, the activity of the sperm is reduced so that they are less able to swim to find an egg. When the person recovers from the disease the sperm regain their activity but, if a male has had a sexually transmitted disease a few times, the tubes carrying the sperm may be scarred due to the infection and block the path of the sperm.

Tuberculosis can also affect both male and female reproductive systems, blocking the path of sperm in males and causing infections in the oviducts and uterus in females.

Diseases can also affect the development of the foetus in the womb. If the mother has malaria it can kill the foetus as it grows or slow down its development so a smaller baby than normal is born. Tuberculosis during pregnancy may also cause the death of the foetus.

Some diseases can cause damage to the foetus which results in the baby being born with a disability. For example rubella, or German measles (because German doctors first identified it 250 years ago), is a disease which is transmitted by droplets which are coughed or sneezed into the air. It can damage the nervous system of the foetus and produce deafness and blindness. The heart can also be damaged.

If a female has a sexually transmitted disease during pregnancy it can cause blindness, deafness, swollen liver and skin sores in her baby.

A female with AIDS may pass on the virus during pregnancy or at birth and this will damage the immune system of the baby.

11 Why do you think damage to the fallopian tubes causes infertility?

12 Look back to pages 67 and 68, and name the sperm-carrying tubes which may be damaged by sexually transmitted diseases.

13 What type of disease is rubella? Explain your answer.

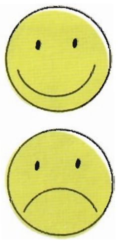
14 Imagine that you were working in a hospital treating babies whose mothers had drunk large amounts of alcohol, smoked cigarettes, taken drugs during pregnancy or had STDs. What features might you expect the babies to have?

Growth and development in young people

Diseases can slow down or stop growth. Then, as the sufferer recovers, growth can begin again. In tuberculosis the disease has an active stage when the lungs are attacked and sufferers begin to cough frequently, develop a fever and lose body mass. The bacteria that cause the disease then become inactive and the sufferer recovers. However, the person still carries the disease and it may start again and enter the blood and spread to other organs of the body. When this happens tuberculosis can be fatal unless the sufferer receives treatment.

The virus causing AIDS can be passed to an infant through the mother's milk.

Malaria can damage the nervous system of a growing child and, if untreated, is often fatal.



Behaviour

When a disease takes hold of the body the sufferer becomes tired and may develop aches and pains and need to rest. AIDS patients may suffer from disorders of the nervous system which make them think more slowly, have trouble with memory and concentration and lose some coordination, which results in being unable to walk and balance properly.

Effect on general health

Someone with tuberculosis may recover for a while and during that time the damaged tissues may recover but develop scar tissue. If the disease becomes active again in the body it may enter the blood and damage the brain, kidneys and bones.

AIDS patients may suffer from a disease of the bones in which they lose minerals and become weaker so that the danger of them breaking increases; they may suffer from kidney disease and diseases of the heart and circulation; they may also have an increased chance of developing cancer.

The microorganisms that cause malaria invade the liver and the red blood cells. As the number of microorganisms increases the person may suffer chills and a fever every few days. There are several types of malaria and in one form the brain, kidneys and lungs become damaged with fatal results.

The sexually transmitted diseases chlamydia, gonorrhea and syphilis result in damage to the reproductive organs. Chlamydia can also infect the eyes causing blindness. Syphilis can cause sores and rashes on the skin.

Fighting disease

Medicine, the science of healing humans, was practised in the ancient civilisations of Egypt, India, China, Greece and Rome and further developed by Islamic scholars in the Middle Ages. Gradually medicine began to develop further in Europe and then eventually around the world. There are two aspects to dealing with disease in medicine: prevention and cure. Immunisation is a major way of preventing some diseases and the use of antibiotics has allowed many people to recover from disease who would otherwise have died.

Figure 7.9 There are healthcare stations in the countryside of many countries where people living in villages can receive help in fighting disease.

The development of immunisation

The process of **immunisation** was developed by Edward Jenner (1749–1825), an English doctor, in 1796. At the time smallpox was a common disease in England. It was caused by a virus that infected the respiratory system and then moved to the skin where it caused rashes, spots and scabs full of pus that were called pustules. Fever also developed and death often followed.

1 What was the main problem with variolation?
2 What could have happened if Jenner had not been right?

Up until that time a process called variolation had been used to try and give protection from smallpox. This had been developed in China where it had been noticed that people with a mild form of smallpox survived and did not get it again. Pus was taken from their sores and put on the skin or up the noses of healthy people who had not had smallpox. It was thought that they too should get a mild form of smallpox and survive. Some people did survive but many developed a severe form and died. However, as there was no better treatment at the time it passed on to Turkey and then into Europe and England.

Edward Jenner discovered that in a village where a smallpox outbreak had occurred, the milkmaids remained unharmed. He found that cattle suffered from a disease similar to smallpox but with milder effects. When the milkmaids milked the cattle they became infected with cowpox. Jenner thought that it gave them protection from smallpox. Jenner planned an investigation to test his idea by modifying the practice of variolation. He took pus from the scabs of a person who had suffered from cowpox and put it into two cuts in the arm of an eight-year-old boy. The boy developed cowpox but quickly recovered. Seven weeks later Jenner took some pus from the scab of a smallpox patient and put some of the pus in two cuts in the boy's arm. The boy did not get smallpox. Jenner called this process **vaccination** after the Latin word for cowpox, 'vaccinia'. Soon vaccination was widely practised and by 1978 the disease had been wiped out worldwide.

Fifty years after Jenner's experiment, Louis Pasteur (1822–1895), a French scientist who made many discoveries about microorganisms, discovered a way of making sheep immune to anthrax. There is no mild form of anthrax so Pasteur looked for ways of weakening the microorganism that produced the fatal disease. He discovered that if the microorganisms were heated and then given to sheep they produced a mild form of the disease. When the sheep recovered he gave them the normal anthrax microorganisms but they did not develop the fatal form of the disease. Weakened or attenuated microorganisms are used to make vaccines called attenuated vaccines in immunisation programmes today.

3 What evidence did Jenner use when he set up his investigation?
4 Which part of the investigation was due to Jenner's creative thinking?
5 What prediction do you think Jenner made before he treated the boy with smallpox?
6 What piece of evidence do you think Pasteur used when he set up his investigation on anthrax?
7 What prediction do you think he made when he heated the anthrax microorganisms?
8 How did he test his prediction?

Figure A The hand of a smallpox patient

The first antibiotic

Bacteria and fungi are two types of microorganisms which can grow on plates of agar jelly that are sealed inside a petri dish. Agar jelly contains the nutrients that bacteria and fungi need to grow and reproduce.

In 1928 Alexander Fleming (1881–1955), a Scottish scientist, was working in a laboratory when he noticed that a plate that had been set aside to grow colonies of certain bacteria also had a green fungus growing on it. At first it looked as if the plate had been spoiled but, when Fleming looked again, he saw that the bacterial colonies near to where the fungus was growing had been destroyed. He reasoned that there was a substance in the jelly, which had come from the fungus, that killed the bacteria. The fungus was called penicillium which means 'little brush'. It was given this name because under the microscope parts of the fungus looked like little brushes. When Fleming extracted the substance from the fungus he called it penicillin.

Figure B Discs of different antibiotics being tested on a plate originally covered with a suspension of a bacterium called *Escherichia coli*. Plates of agar jelly containing bacterial colonies are still used to test antibiotics today.

Fleming tested penicillin on a range of bacteria and found that some were killed and others were not. He then tested penicillin on human white blood cells and found that they were not destroyed by concentrations that killed bacteria. Fleming did not investigate penicillin further but other scientists did and from their work a range of antibiotics has been developed to fight diseases caused by bacteria.

9 Why can bacteria and fungi grow well on agar?

10 Why was Fleming's agar plate thought to have been spoiled?

11 Why did Fleming believe the fungus made a substance that killed bacteria?

12 Look at Figure B. Which disc has the strongest antibiotic? Explain your answer.

13 How did the results of Fleming's investigation on human white blood cells suggest that penicillin could be useful?

14 Which Scientific Enquiry skill (see pages 3–4) did Fleming use first which gave him an idea for an investigation?

15 Which Scientific Enquiry skill was Fleming using when he reasoned that there was something in the jelly that had come from the fungus that was killing the bacteria?

16 What prediction do you think Fleming made when he tested bacteria with penicillin?

17 What scientific knowledge and understanding did he use to make the prediction?

18 When Fleming switched his attention to white blood cells, which Scientific Enquiry skill was he using and what do you think went through his mind?

SUMMARY

- Diet can affect conception and pregnancy (*see page 81*).
- Diet can affect growth and development (*see page 81*).
- Diet can affect behaviour (*see page 82*).
- Diet can affect health (*see page 82–3*).
- Drugs can affect conception and pregnancy (*see page 84*).
- Drugs can affect growth and development (*see page 85*).
- Drugs can affect behaviour (*see page 85*).
- Drugs can affect health (*see page 86*).
- Disease can affect conception and pregnancy (*see page 88*).
- Disease can affect growth and development (*see page 89*).
- Disease can affect behaviour (*see page 89*).
- Disease can affect health (*see page 89*).

End of chapter questions

In the top row, this table shows the populations of certain regions in the world in one year in the early 21st century. The other rows show the deaths in these regions due to some of the diseases and disorders discussed in this chapter.

Disease or disorder	**Africa 738 million**	**South East Asia 1672 million**	**Eastern Mediterranean 520 million**	**Europe 883 million**
tuberculosis	405 000	519 000	111 000	77 000
HIV/AIDS	1 651 000	206 000	31 000	31 000
malaria	806 000	36 000	39 000	0
lack of protein and energy in the diet	111 000	55 000	26 000	5000
alcohol-related disorder	4000	17 000	3000	26 000
drug-related disorder	3000	27 000	34 000	15 000

***Source*: World Health Organisation**

1 Which region has the largest population?
2 In which region is there the largest number of deaths from malaria?
3 In which region is there the largest number of deaths from tuberculosis?
4 What is the cause of the largest number of deaths in Africa?
5 **a)** How many people die of alcohol and drug-related disorders in Europe?
b) How many people die of alcohol and drug-related disorders in South East Asia?
c) Which region do you think has the larger alcohol and drug-abuse problem? Explain your answer.
6 Disease prevention is expensive so poor countries have fewer disease-prevention programmes and suffer a greater number of deaths each year from disease.

6 Disease prevention is expensive so poor countries have fewer disease-prevention programmes and suffer a greater number of deaths each year from disease.

a) What is the total number of deaths from tuberculosis and AIDS:

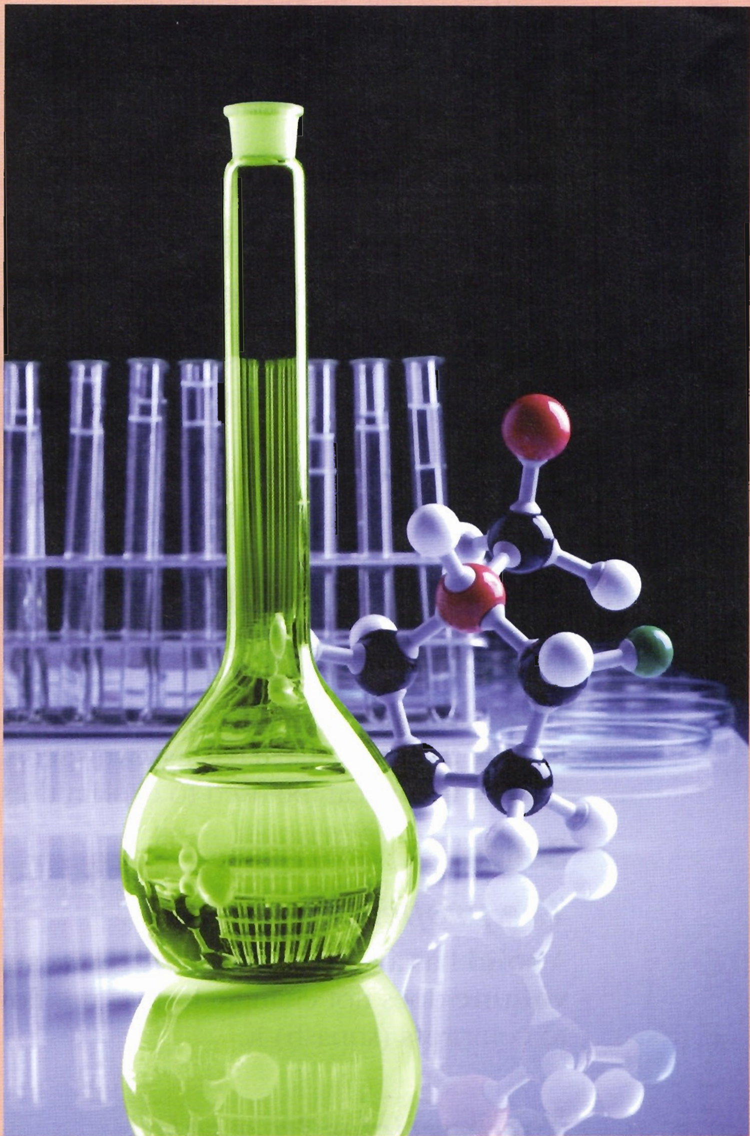
i) in Africa

ii) in Europe?

b) If we say for the purpose of this question that the populations are similar (although there is a 100 million difference), how many deaths could be saved if Africa had the same disease-prevention programme as Europe?

c) What other threats to health in Africa need to be reduced?

CHEMISTRY



8 The particle theory

- The particle theory of matter
- The properties of matter and the particle theory
- When states of matter change
- Pressure
- Diffusion

The particle theory of matter

The particle theory states that matter is made from **particles**. The particles are so tiny that they cannot be seen with the naked eye. Different substances are made from different particles and the particles have different sizes. The particles are made from **atoms** and **molecules**.

The properties of matter and the particle theory

There are three states of matter: solids, liquids and gases. Each of the three states has its own special properties. The particle theory can be used to explain these properties.

Solids

The properties of solids

A **solid** has a definite **mass**, a definite shape and its **volume** does not change. It does not flow and it is hard to compress (squash) it.

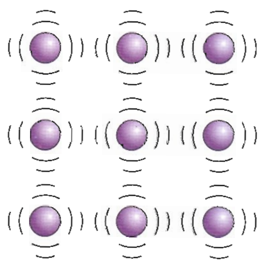


Figure 8.1 The arrangement of particles in a solid

The particles in a solid

In solids, strong forces of attraction hold the particles together in a three-dimensional structure. In many solids the particles form an orderly arrangement called a lattice. The particles in solids can move a little. They do not change position but vibrate to and fro about one position.

Figure 8.2 These crystals found in Shark's Mouth Cave, Mexico demonstrate the properties of a solid. They have a definite shape and volume and cannot be squashed.

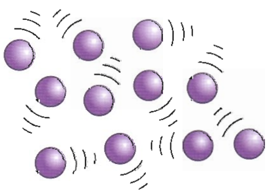
The particles and properties

The strong forces of attraction between the particles stop the particles from moving around each other and making the solid flow. As the particles cannot move in this way the shape of the solid cannot change. The particles are close together so they need to be compressed hard to get them any closer.

Liquids

The properties of liquids

A **liquid** has a definite mass and its volume does not change. It is hard to compress but it flows easily. The shape of the liquid varies and depends on the shape of the container holding it.



liquid particles have some freedom and can move around each other

Figure 8.3 The arrangement of particles in a liquid

The particles in a liquid

In liquids, the forces that hold the particles together are weaker than in solids. The particles in a liquid can change position by moving around each other.

Figure 8.4 The water in this waterfall in Croatia demonstrates the properties of a liquid. It has definite volume and flows easily but is contained in pools by the rock around it.

1 You have a rock, a jug of water and a bucket. You place the rock in the bucket and then pour the water over it. What change of shape would you expect to find and why?

The particles and properties

The weaker forces of attraction between the particles allows them to move more and this explains why the liquid can flow. As the forces are not strong enough for the liquid to keep a definite shape, it gains support from the walls of its container and takes up the shape of any container into which it is poured. The particles are close together so they need to be compressed hard to get them any closer.

Gases

The properties of gases

A **gas** has a definite mass but its volume can vary and it takes up the shape of the container holding it. It flows easily and it is easy to compress.

The particles in a gas

In gases, the forces of attraction between the particles are very small and the particles can move away from each other and travel in all directions. When they hit each other or the surface of their container they bounce and change direction.

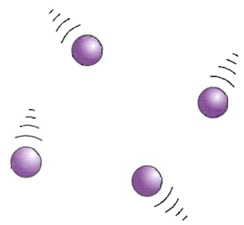


Figure 8.6 The arrangement of particles in a gas

Figure 8.5 When gas, such as nitrogen oxide shown here, escapes it spreads out in air.

2 You have 500 cm^3 of a liquid and 500 cm^3 of a gas. You place the liquid and the gas into separate litre bottles. Do the liquid and the gas occupy the same volume in the two bottles? Explain your answer.

The particles and properties

The weakness of the forces between the particles in a gas lets them move freely so that they can move far apart or come closer together. This variation in the distance between the particles explains why the volume of a gas can change. The larger distances between the gas particles also means that when they are compressed there is plenty of space into which they can move and this makes compression easy. The weak forces also allow the gas to flow easily. When it is placed in a container the particles can spread out in all directions as they hit each other and the container walls so the whole of the space inside the container is occupied by moving gas particles.

When states of matter change

3 Some of the physical changes of matter can be arranged in pairs to show that they are reversible reactions.
a) Identify a pair of physical changes between a solid and liquid.
b) Identify two pairs of physical changes between a liquid and a gas.

The state of matter of a substance can be changed. This type of change is called a physical change and is a reversible reaction. Melting, freezing, evaporating, boiling, condensing, sublimation and dissolving are all examples of physical change.

Melting

When a solid is heated to its **melting point** it loses shape and starts to flow. This is due to the energy supplied by the heat, making the particles vibrate more strongly so they push each other further away. This weakens the forces of attraction between the particles and allows them to move around each other.

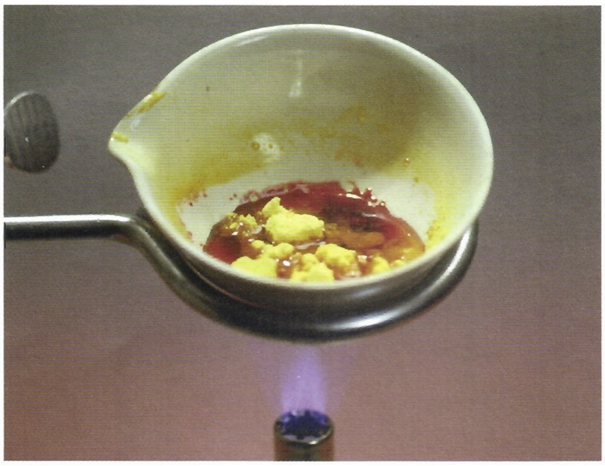


Figure 8.7 When sulfur reaches a temperature of 115 °C it melts.

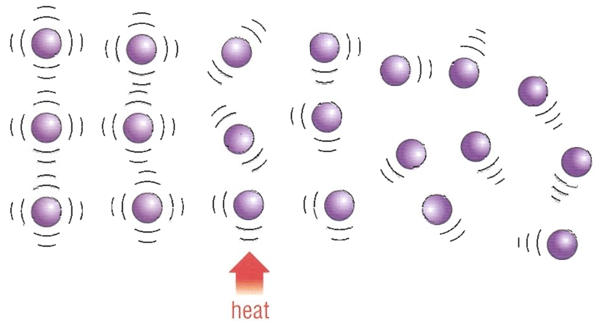


Figure 8.8 The particle arrangement in a solid (on the left) changes as the heat turns it into a liquid (on the right).

Freezing

When a liquid is cooled to its **freezing point** the particles lose so much energy that they can no longer move around each other. The only movement possible is the vibration to and fro about one position in a lattice and the liquid becomes a solid.

4 a) Draw a diagram to show how the arrangement of the particles in a liquid changes when it freezes into a solid.
b) What causes the change in the arrangement of the particles?

Figure 8.9 As the temperature fell below 0 °C water dripping off these twigs froze and formed icicles.

Evaporating

A liquid can turn into a gas over a range of temperatures without boiling by a process called **evaporation**. In this process some of the liquid at the surface changes into a gas and mixes with the air. It happens because the particles in a liquid have different amounts of energy and those with the most energy move the fastest. At the surface these fast-moving particles break away from the others, escape into the air and form a gas.

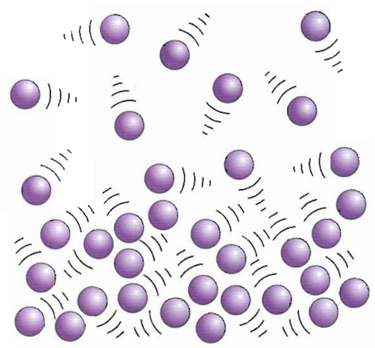


Figure 8.10 Particles evaporating from the surface of a liquid

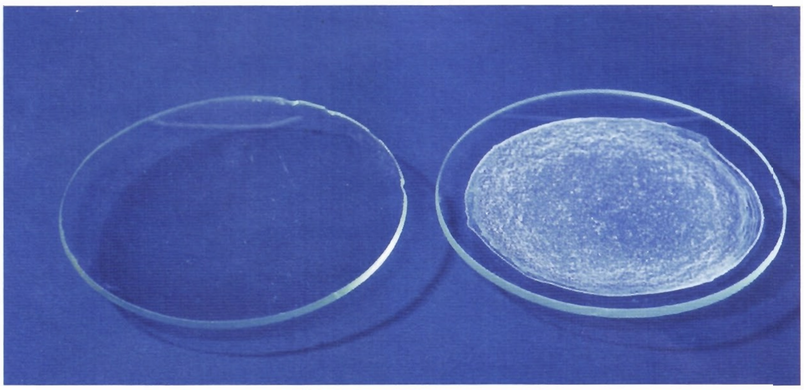


Figure 8.11 When evaporation occurs in a solution (see page 127) the solvent escapes into the air and the solute remains behind.

Boiling

When a liquid reaches its **boiling point** bubbles of gas form in it which rise to the surface and burst into the air. This process is called **boiling**. If the boiling liquid is heated more strongly, its temperature does not rise but it boils more quickly. The heat makes all the particles in the liquid move more quickly and the fastest-moving particles escape from the surface of the liquid or collect in the liquid to form bubbles which then rise to the surface and burst into the air. These fast-moving particles released from the liquid form a gas.

5 In what ways are evaporation and boiling:
a) similar
b) different?

6 Draw a diagram to show how you think a bubble in a liquid would look according to particle theory.

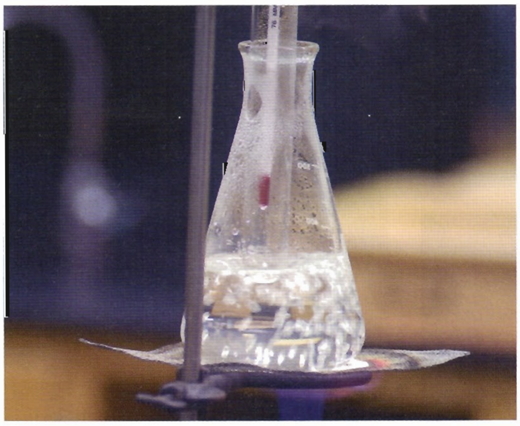


Figure 8.12 The rising bubbles in the liquid in this flask show the liquid has reached its boiling point.

Condensing

If a gas cools down far enough it **condenses** and forms a liquid. The particles in a gas lose some of the energy which allows them to move so quickly and they slow down so much that they can no longer bounce off each other when they meet. They stay close to each other and form a liquid.

7 Draw a diagram to show how the arrangement of the particles in a gas changes when the gas condenses and forms a liquid.

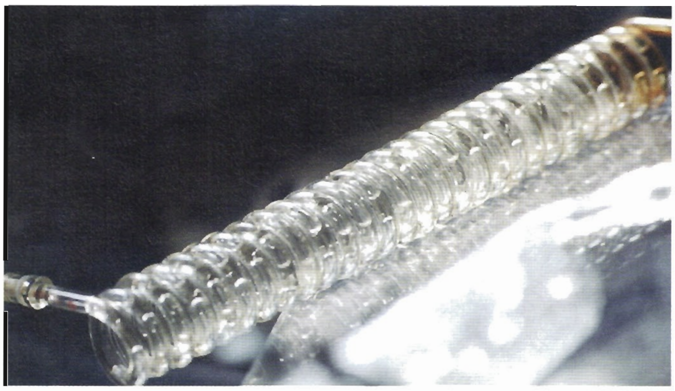


Figure 8.13 Steam passing through this condenser has cooled and condensed to form water.

Sublimation

A few substances can change from a solid to a gas or a gas to a solid without forming a liquid. This process is called **sublimation**. When the solid changes into a gas the forces which bind the particles together are quickly lost and they move away from each other completely. When a gas forms directly into a solid the particles lose their energy so quickly that they come together and are held by the forces between them.

8 a) In sublimation which state of matter is absent?

b) Draw a diagram to show how the arrangement of the particles in a substance changes when sublimation takes place.

Figure 8.14 When solid iodine is heated it sublimes to form a gas. This is always done in a fume cupboard.

Dissolving

When a solid dissolves in a liquid it seems to disappear into it (see Figure 8.16). If it is a coloured substance it may colour the liquid. However it does not disappear, its particles simply separate and spread out through the liquid. This is possible because the liquid has gaps between its particles and it is into them that the particles of the dissolving substance pass.

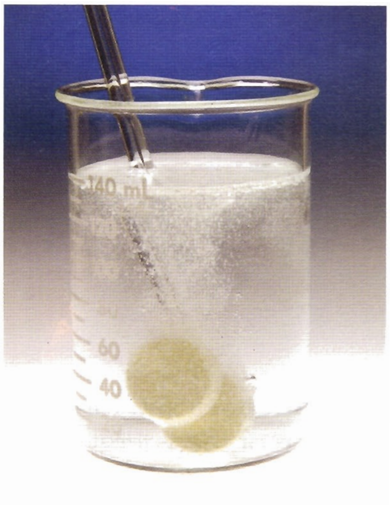


Figure 8.15 These tablets, placed in water, are starting to dissolve.

9 Draw a series of diagrams to show how the arrangement of the particles in a solution changes as the solvent evaporates and the solute remains behind.

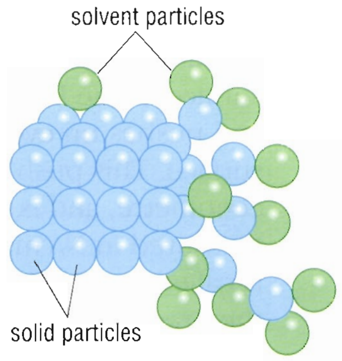


Figure 8.16 Dissolving

Gas pressure

Solids can generate **pressure** – think of a brick pressing down on your toes. Liquids can generate pressure too. A dam has to be built with thick walls to withstand the pressure of the water that collects in the reservoir behind it. Gases also generate pressure due to the action of their particles.

A gas contains millions of quickly moving particles. Every second, large numbers are bouncing off the walls of the gas container. The force of these particles as they push against the surface generates the gas pressure.

If the gas is heated the particles move faster and bounce off the container surface more frequently and with more force, so the gas pressure rises. When the gas is cooled the particles move more slowly. They bounce off the container's surface less frequently and with less force and the gas pressure falls.

When a gas is squashed into a smaller volume but its temperature is kept the same, as shown in Figure 8.17, the particles have less space in which to move. They bounce off the container walls more frequently and the gas pressure rises.

10 What two things can make the pressure of a gas rise?

11 a) What happens to the gas pressure if the gas is released from a small container into a large container?

b) Why does the gas pressure in part **a)** change?

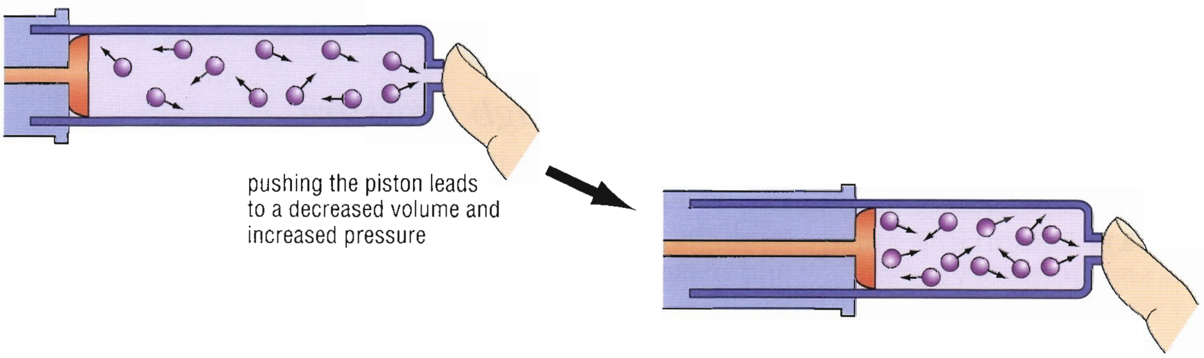


Figure 8.17 Gas pressure can be explained using the particle theory.

Atmospheric pressure

The atmosphere is a mixture of gases that covers the surface of the Earth. The atmosphere is 1000 km thick and pushes on every square centimetre of the Earth's surface. This push is a force on a specific area, the square centimetre, and is known as atmospheric pressure. It is measured in N/cm^2. The atmospheric pressure at sea level is called standard pressure and is about $10\,N/cm^2$. It is the pressure at which the boiling point of any substance is measured. At the top of very high mountains the atmospheric pressure is less than at sea level.

Boiling and low pressure

12 If you boiled water at the top of a mountain, would you expect it to boil at 100 °C? Explain your answer.

If a flask containing a liquid is connected to a vacuum pump and some of the air above the liquid is sucked out, there is less air inside the flask to push on the surfaces and the air pressure is smaller.

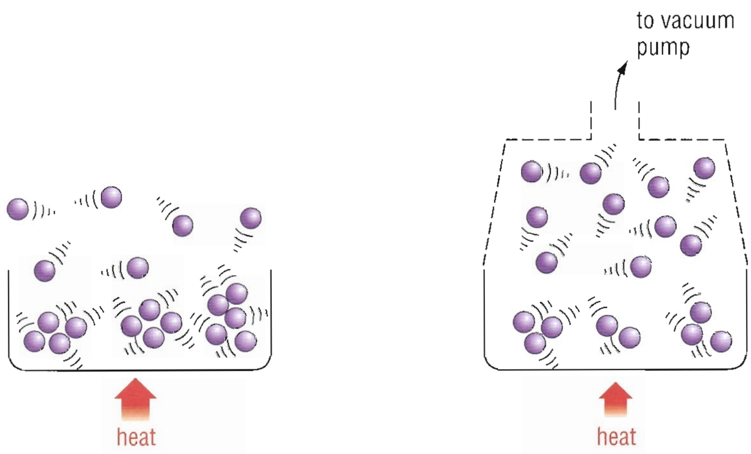


Figure 8.18 Lowering the pressure lowers the boiling point of a liquid.

Figure 8.19 The lid on this pan of boiling water is being pushed up by the steam.

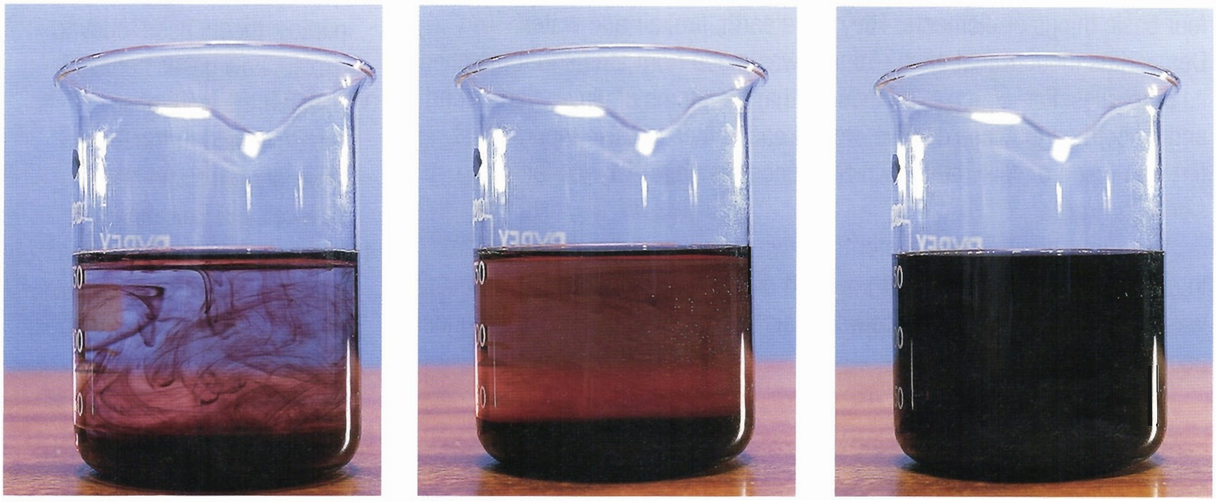
The reduced air pressure allows evaporation to take place more quickly and less heat is needed to make the liquid boil. Lowering the atmospheric pressure on a liquid lowers its boiling point.

Boiling and high pressure

When a gas gets hot it expands and increases its pressure on the surfaces around it. If water is boiled in a pan with a lid, the steam escaping from the water pushes on the lid and makes it rise – allowing the gas to escape.

Diffusion

Diffusion is a process in which one substance spreads out through another. It occurs in liquids and gases. For example, if you put a drop of ink in a beaker of water the ink spreads out through the water by diffusion and colours it (see Figure 8.20).



At the start After an hour After a day

Figure 8.20 Black ink diffusing through a beaker of water

13 Draw a diagram to show how the particles of one substance diffuse through the particles of another.

The gases escaping from food cooking in the kitchen can move by diffusion to other rooms in the home. The moving particles in the different liquids move around each other and the particles in the different gases bounce off each other. These movements eventually spread all the particles of one substance evenly through the other. Liquids are denser than gases and this makes diffusion in liquids much slower than diffusion in gases.

Steps on the way to the particle theory

Democritus (about 470–380 BCE) was a Greek philosopher who thought about the structure of matter. He wondered what would happen if you took a substance and divided it into two and then carried on dividing. He believed that a tiny piece would be produced that could not be divided. He called this tiny piece of matter an atom. The word 'atom' means indivisible.

In Ancient Greece it was believed that everything was made up from four basic things or elements. They were earth, fire, air and water. Democritus thought that each element was made from atoms that matched its properties. For example, he thought that the atoms of water were round and smooth so they could move around each other. He also thought that fire was made of spiky atoms which caused the pain that was felt when skin was burnt.

About four hundred years later there was a Greek inventor called Hero. In one of his inventions, a wind-powered organ, he had an air pump which was driven by a windmill and delivered air to a row of pipes so that sounds could be made.

1 How might Democritus have described the shape of the atoms of the Greek 'element' earth?
2 How does Hero's idea about the air compare with the particle theory used today to explain how gases behave?
3 How did the work of scientists like Boyle add to the Greek ideas of atoms and help Maxwell and Boltzmann?
4 Why was it logical to develop the ideas that solids and liquids were made of particles too?

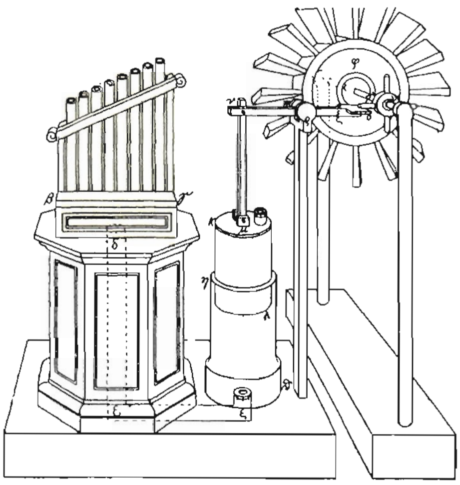


Figure A Hero's wind organ

Table A

Pressure/atmospheres	Volume/litres
1.0	12
1.5	8
2.0	6
2.5	5
3.0	4

Hero used the idea about atoms to explain his observations about air. He thought that the air was made of tiny particles with space between them. He believed that this idea explained how air could be squashed. When air was squashed the particles moved closer together and there was less space between them. He was unable to test his ideas because the Greeks at that time did not think that experiments had any importance.

Robert Boyle (1627–1691) was both a chemist and a physicist. In one of his experiments he investigated how the volume of a gas changed when he changed the pressure acting on it. He knew that a change in temperature could make a gas expand or contract so he kept the gas he was working on at the same temperature during the experiment. Table A shows some results which have been produced by repeating Boyle's experiment. The units in the table are the units Boyle would have used, which are called atmospheres, so that the data looks as it might have done in Boyle's time.

Boyle also believed that his observations could be explained by gases being made of atoms.

James Clerk Maxwell (1831–1879), a Scottish physicist, and Ludwig Boltzmann (1844–1906), an Austrian physicist, studied the results of experiments on gases and the idea of gases being made of atoms. They took the idea that gases were made of particles and performed calculations on the speed of particles. Their calculations matched the way gases behaved and from them the particle theory of matter was developed.

5 What example of creative thinking did Hero use in his explanation of what happened when air is squashed?

6 The pressure, temperature and volume of a gas are all variables.

a) Which variable did Boyle:

i) control

ii) change

iii) measure?

b) What trend or pattern can you see in Boyle's results?

7 **a)** How does the volume of the gas change when the pressure is increased:

i) from 1 atmosphere to 2 atmospheres

ii) from 1.5 atmospheres to 3 atmospheres?

b) What relationship do the two changes in pressure and volume in part **a)** show?

8 **a)** Draw a line graph of the information in Table A.

b) Use your line graph to predict the volume of the gas when the pressure is 4 atmospheres.

SUMMARY

- The particle theory states that matter is made from particles (*see page 96*).
- The properties of solids, liquids and gases can be explained by the particle theory (*see pages 96–99*).
- The physical changes of state can be explained by the particle theory (*see page 99*).
- The pressure of a gas can be explained by the particle theory (*see page 103*).
- Diffusion can be explained by the particle theory (*see page 105*).

End of chapter questions

1 **a)** Will evaporation be quicker from a large surface area of liquid or a small surface area?

b) Use the particle theory to explain the reason for your answer in part **a)**.

c) Devise an investigation to test your answer.

2 Why does a bicycle tyre get harder when you pump it up?

9 Elements and atoms

- The discovery of the elements
- The link between elements and atoms
- The properties of elements
- Chemical symbols
- The first twenty elements of the periodic table

One of the main activities in chemistry is breaking down substances to discover what they are made of. During the course of this work chemists have discovered that some substances cannot be broken down into simpler substances by physical changes or chemical reactions. These substances are called **elements**.

The discovery of the elements

Before 1669 the following elements had already been discovered: carbon, sulfur, iron, copper, arsenic, silver, tin, antimony, gold, mercury and lead. Some had been known for thousands of years, although they had not been recognised as elements. The order in which the other elements were discovered is shown in Table 9.1 on page 109. This table uses mainly European historical data but it is known that the Chinese and people in Muslim countries also studied chemistry, so some of the elements could have been discovered by them at an earlier date.

Use Table 9.1 on pages 109–111 to answer these questions.

1 How many elements were discovered in:
   a) the 17th century or earlier
   b) the 18th century
   c) the 19th century?

2 Which three scientists discovered the most elements?

3 How many Swedish scientists discovered new elements?

4 Which UK scientist discovered the most elements?

Table 9.1 The discovery of the elements

Date	Element	Discoverer	Brief description
1669	Phosphorus	H. Brand (Germany)	white, red or black solid
1737	Cobalt	G. Brandt (Sweden)	reddish metal
1746	Zinc	A. S. Marggraf (Germany)	blue-white metal
1748	Platinum	A. de Ulloa (Spain)	blue-white metal
1751	Nickel	A. F. Cronstedt (Sweden)	silver-white metal
1753	Bismuth	C. F. Geoffroy (France)	silver-red metal
1766	Hydrogen	H. Cavendish (UK)	colourless gas
1771–1774	Oxygen	C. W. Scheele (Sweden) J. Priestley (UK)	colourless gas
1772	Nitrogen	D. Rutherford (UK)	colourless gas
1774	Chlorine	C. W. Scheele (Sweden)	green-yellow gas
1774	Manganese	J. G. Gahn (Sweden)	red-white metal
1781	Molybdenum	P. J. Hjelm (Sweden)	silver-grey metal
1783	Tellurium	F. J. Muller (Austria)	silver-grey solid
1783	Tungsten	J. J. de Elhuya, F. de Elhuya (Spain)	grey metal
1789	Zirconium	M. H. Klaproth (Germany)	shiny, white metal
1789	Uranium	M. H. Klaproth (Germany)	blue-white metal
1794	Yttrium	J. Gadolin (Finland)	shiny, grey metal
1795	Titanium	M. H. Klaproth (Germany)	silvery metal
1798	Beryllium	N-L Vauquelin (France)	brown powder
1798	Chromium	N-L Vauquelin (France)	silvery metal
1801	Niobium	C. Hatchett (UK)	grey metal
1802	Tantalum	A. G. Ekeberg (Sweden)	silvery metal
1803	Cerium	J. J. Berzelius, W. Hisinger (Sweden) M. H. Klaproth (Germany)	grey metal
1803	Palladium	W. H. Wollaston (UK)	silver-white metal
1804	Rhodium	W. H. Wollaston (UK)	grey-blue metal
1804	Osmium	S. Tennant (UK)	blue-grey metal
1804	Iridium	S. Tennant (UK)	silver-white metal
1807	Potassium	H. Davy (UK)	silver-white metal
1807	Sodium	H. Davy (UK)	silver-white metal
			(continued)

Date	Element	Discoverer	Brief description
1808	Magnesium	H. Davy (UK)	silver-white metal
1808	Calcium	H. Davy (UK)	silver-white metal
1808	Strontium	H. Davy (UK)	silver-white metal
1808	Barium	H. Davy (UK)	silver-white metal
1808	Boron	J. Gay-Lussac, L. Thernard (France)	dark brown powder
1811	Iodine	B. Courtois (France)	grey-black solid
1817	Lithium	J. A. Arfwedson (Sweden)	silver-white metal
1817	Cadmium	F. Stromeyer (Germany)	blue-white metal
1818	Selenium	J. J. Berzelius (Sweden)	grey solid
1824	Silicon	J. J. Berzelius (Sweden)	grey solid
1825–1827	Aluminium	H. C. Oersted (Denmark) F. Wohler (Germany)	silver-white metal
1826	Bromine	A. J. Balard (France)	red-brown liquid
1829	Thorium	J. J. Berzelius (Sweden)	grey metal
1830	Vanadium	N. G. Sefstrom (Sweden)	silver-grey metal
1839	Lanthanum	C. G. Mosander (Sweden)	metallic solid
1843	Terbium	C. G. Mosander (Sweden)	silvery metal
1843	Erbium	C. G. Mosander (Sweden)	silver-grey metal
1844	Ruthenium	K. K. Klaus (Estonia)	blue-white metal
1860	Caesium	R. W. Bunsen, G. R. Kirchhoff (Germany)	silver-white metal
1861	Rubidium	R. W. Bunsen, G. R. Kirchhoff (Germany)	silver-white metal
1861	Thallium	W. Crookes (UK)	blue-grey metal
1863	Indium	F. Reich, H. T. Richter (Germany)	blue-silver metal
1868	Helium	J. N. Lockyer (UK)	colourless gas
1875	Gallium	L. de Boisbaudran (France)	grey metal
1878	Ytterbium	J-C-G de Marignac (Switzerland)	silvery metal
1878–1879	Holmium	J. L. Soret (France) P. T. Cleve (Sweden)	silvery metal
1879	Scandium	L. F. Nilson (Sweden)	metallic solid
1879	Samarium	L. de Boisbaudran (France)	light grey metal
1879	Thulium	P. T. Cleve (Sweden)	metallic solid

Date	Element	Discoverer	Brief description
1880	Gadolinium	J-C-G de Marignac (Switzerland)	silver-white metal
1885	Neodymium	C. Auer von Welsbach (Austria)	yellow-white metal
1885	Praseodymium	C. Auer von Welsbach (Austria)	silver-white metal
1886	Dysprosium	L. de Boisbaudran (France)	metallic solid
1886	Fluorine	H. Moissan (France)	green-yellow gas
1886	Germanium	C. A. Winkler (Germany)	grey-white metal
1894	Argon	W. Ramsay, Lord Rayleigh (UK)	colourless gas
1898	Krypton	W. Ramsay, M. W. Travers (UK)	colourless gas
1898	Neon	W. Ramsay, M. W. Travers (UK)	colourless gas
1898	Polonium	Mme M. S. Curie (Poland/France)	metallic solid
1898	Xenon	W. Ramsay, M. W. Travers (UK)	colourless gas
1898	Radium	P. Curie (France), Mme M. S. Curie (Poland/France), M. G. Bermont (France)	silvery metal
1899	Actinium	A. Debierne (France)	metallic solid
1900	Radon	F. E. Dorn (Germany)	colourless gas
1901	Europium	E. A. Demarçay (France)	grey metal
1907	Lutetium	G. Urbain (France)	metallic solid
1917	Protactinium	O. Hahn (Germany), Fr L. Meitner (Austria), F. Soddy, J. A. Cranston (UK)	silvery metal
1923	Hafnium	D. Coster (Netherlands) G. C. de Hevesy (Hungary/Sweden)	grey metal
1925	Rhenium	W. Noddack, Fr I. Tacke, O. Berg (Germany)	white-grey metal
1937	Technetium	C. Perrier (France), E. Segre (Italy/USA)	silver-grey metal
1939	Francium	Mlle M. Percy (France)	metallic solid
1940	Astatine	D. R. Corson, K. R. Mackenzie (USA), E. Segre (Italy/USA)	metallic solid
1945	Promethium	J. Marinsky, L. E. Glendenin, C. O. Corgell (USA)	metallic solid

The link between elements and atoms

So far we have seen that an element is a substance that cannot be broken down by physical changes or chemical reactions into a simpler form of matter. In the previous chapter we learnt that particles are made of molecules and atoms and that atoms are the particles from which all forms of matter are made. You also learnt that the word 'atom' means indivisible. This leads us to look for a link between an element, a substance which cannot be broken down into simpler substances, and an atom, a particle from which all things are made.

The link is that each element is made of one particular type of atom which has its own particular properties. The properties of the atom of the element also give the element its own particular properties.

5 Why do elements have different properties?

The properties of elements

Figure 9.1 Mercury and bromine are liquid at room temperature.

There are only two elements that are liquid at room temperature and standard pressure. They are mercury and bromine. Eleven elements are gases under normal conditions. All the others are solids.

Each element has its own special properties. For example, sodium is a soft, silvery-white metal with a melting point of 98 °C and a boiling point of 884 °C and chlorine is a yellow-green gas with a melting point of –101 °C and a boiling point of –34 °C.

Most substances are made from two or more elements that are joined together.

These substances are called **compounds**. When elements form compounds they no longer display their own special properties. Instead the compound has its own special properties. For example, when sodium and chlorine form the compound sodium chloride they form a white solid with a melting point of 801 °C and a boiling point of 1420 °C that easily forms crystals. You can learn more about compounds in Chapter 10.

Probably the most spectacular use of the properties of elements is in fireworks. Compounds of some elements are used to make fireworks. When they are heated they produce light of various colours (see Table 9.2).

Figure 9.2 A dazzling firework display

Table 9.2 The colours produced by elements when heated

Element	Colour
aluminium	silvery-white
barium	apple green
calcium	orange
caesium	blue
copper	green
lithium	red
magnesium	white
sodium	golden yellow
rubidium	violet-red
strontium	red

6 Iron and titanium are two elements that are used in compounds to make sparks and zinc is used in compounds to make smoke. Which other elements could you use in compounds to make a firework that produced green and red sparks and finished with blue smoke?

Chemical symbols

The first chemists were called alchemists. Two of their main activities were investigating materials in an attempt to find a way to make gold or a medicine which would extend the human lifespan. They wrote down details of their investigations using symbols to represent the substances they used or produced. The use of symbols saved them time. Figure 9.3 on page 114 shows a few of the alchemists' symbols. Some of the symbols were deliberately mysterious as the alchemists really wanted to keep their work a secret – just in case they discovered how to make gold or a medicine that would make them live forever!

Figure 9.3 Alchemists' symbols

The alchemists also gave many of the substances a number of different names, again to increase secrecy, and this led to confusion when the science of chemistry began properly.

It was decided that each substance used in an investigation or produced from it should be clearly identified by one name only so that reports of investigations could be clearly understood.

In 1787 Lavoisier and three other scientists set out the names of all the substances used in chemical investigations in a 300-page book.

In 1813 Jöns Jakob Berzelius introduced the symbols we still use today to represent the elements. Each element was identified by the first letter of its name. If two or more elements began with the same letter, another letter in the name was also used.

Some of the symbols are made from old names for the elements. Iron, for example, had an old name of ferrum and the symbol Fe is made from it. Silver was known as argentum and its symbol is Ag.

Sodium is known as natrium, and potassium is known as kalium in Latin and some other languages and the symbols for sodium and potassium were made from these names. The symbol for sodium is Na and the symbol for potassium is K.

The elements have received their names from a variety of sources. Some elements, such as chlorine (from the Greek word meaning green colour) and bromine (from the Greek word for stench), are named after their properties. Other elements are named after places. The places may be as small as a village – strontium is named after Strontian in Scotland – or as large as a planet – uranium is named after the planet Uranus. A few elements, such as einsteinium, are named after people.

7 Why do some elements have two letters for their chemical symbol and others have only one?

8 Why isn't the symbol for silver S and the symbol for potassium P?

9 How did some of the elements get their names?

The first twenty elements in the periodic table

After a large number of elements had been identified scientists began arranging them into order based on their properties, such as mass, and a table called the periodic table was produced. It is called the periodic table because as you move along the rows elements with certain properties occur periodically. We will look at how this occurs in more detail in *Checkpoint Science 3* but for now we just need to know that such a table exists and is very widely used. For example, there may be a copy of the periodic table on the wall of your laboratory. Figure 9.4 shows part of the periodic table.

You do need to know the first twenty elements in the periodic table now so for easy reference their names and chemical symbols are given in Table 9.3. Note that you read down the left-hand column first, then sodium follows neon and you read down the right-hand column.

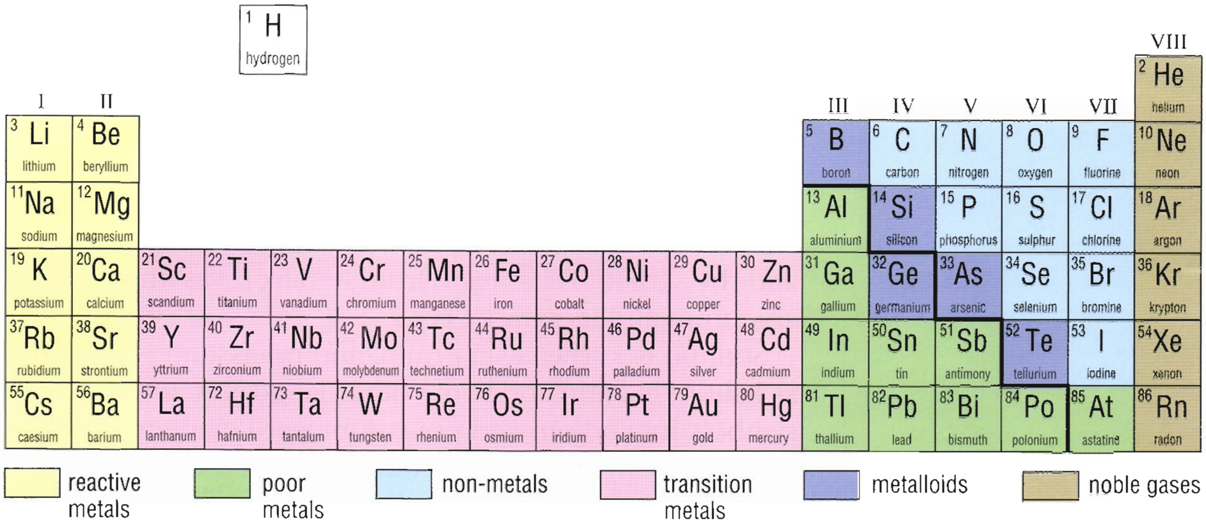


Figure 9.4 Part of the periodic table showing six classification groups of elements

10 Carbon and sulfur were discovered before 1669 but the other elements were discovered afterwards.

a) What was the date of discovery of the other elements in Table 9.3?

b) Arrange the elements in the order in which they were discovered.

Table 9.3 The names and chemical symbols of the first twenty elements of the periodic table (sodium follows on from neon)

	Name	Symbol		Name	Symbol
1	hydrogen	H	11	sodium	Na
2	helium	He	12	magnesium	Mg
3	lithium	Li	13	aluminium	Al
4	beryllium	Be	14	silicon	Si
5	boron	B	15	phosphorus	P
6	carbon	C	16	sulfur	S
7	nitrogen	N	17	chlorine	Cl
8	oxygen	O	18	argon	Ar
9	fluorine	F	19	potassium	K
10	neon	Ne	20	calcium	Ca

SUMMARY

- Substances can be broken down into elements (*see page 108*).
- Each element is made from atoms which are different from the atoms of other elements (*see page 112*).
- Each element has its own special properties (*see page 112*).
- When elements combine to make a compound, the compound has different properties from the elements from which it is made (*see page 112*).
- There is a chemical symbol for each element (*see page 113*).
- The first twenty elements of the periodic table begins with hydrogen and ends with calcium (*see pages 115 and 116*).

End of chapter questions

1 Look at Table 9.1 and answer the following questions.

a) Which elements are gases at room temperature?

b) Which gaseous elements are coloured and what are their colours?

c) Mercury is one of two liquid elements. What is the other and when was it discovered?

d) What are the most common colours of elements?

e) Name the elements that are red or reddish.

f) Name the elements that appear partly blue.

2 Table 9.4 shows the main elements making up the Earth's crust, the air and the human body. Elements in quantities less than 1% are not shown but may be present in very small amounts.

Table 9.4 The main elements in the Earth's crust, the air and the human body

Element	Earth's crust	Air	Human body
aluminium	8.2%	–	–
carbon	–	–	18%
calcium	4.5%	–	1.5%
hydrogen	–	–	10%
iron	5.6%	–	–
magnesium	2.3%	–	–
nitrogen	–	78%	3%
oxygen	46.1%	21%	65%
potassium	2%	–	–
silicon	28. 2%	–	–
sodium	2.4%	–	–

a) Arrange the elements in the human body in order starting with the most plentiful.

b) Arrange the elements in the Earth's crust in order starting with the most plentiful.

c) Which element is found in large amounts in the Earth's crust, the air and the human body?

d) How does the amount of calcium in the Earth's crust compare with the amount in the human body?

The main elements in the Sun, starting with the most plentiful, are hydrogen, helium, oxygen, carbon, nitrogen, silicon, magnesium, neon, iron and sulfur.

e) Which of the main elements found in the Sun are not found in Table 9.4?

f) Which of the main elements in the Sun are also main elements in the human body?

g) Which of the main elements in the Sun are only found as main elements in the Earth's crust and not in the air or the human body?

10 Elements, compounds and mixtures

- A mixture of elements
- From elements to a compound
- Chemical reactions and equations
- Chemical names of compounds
- Different types of mixtures
- Separating mixtures

Chemists deal with elements, compounds and mixtures in their investigations. In the last chapter we looked at elements and in this one we will look at what happens when we mix two elements and then make them into a compound. We will also look at different types of mixtures and how to separate them.

Mixing elements

Each element has its own particular properties. Sulfur, for example, is yellow and if shaken with water it will tend to float. Iron is black and magnetic and produces hydrogen when it is placed in hydrochloric acid.

If the two elements are mixed together, a grey-black powder is produced. The colour depends on the amount of sulfur mixed with the iron. Although the two elements are close together, their properties do not change. If a magnet is passed over the **mixture**, iron particles leap up and stick to it. If the mixture is shaken with water the sulfur will tend to float.

Figure 10.1 Black iron (left) and yellow sulfur (centre) mix to form a grey-black powder (right).

From elements to a compound

Figure 10.2 When iron and sulphide react together, they form a product called iron sulfide

If the mixture of iron and sulfur is heated a chemical reaction takes place. The atoms of iron and sulfur join together and form a compound called iron sulfide. It does not have the yellow colour of the sulfur or the magnetic properties of the iron. It has its own properties – it is a black non-magnetic solid. All compounds have properties which differ from the elements that formed them.

Chemical reactions and equations

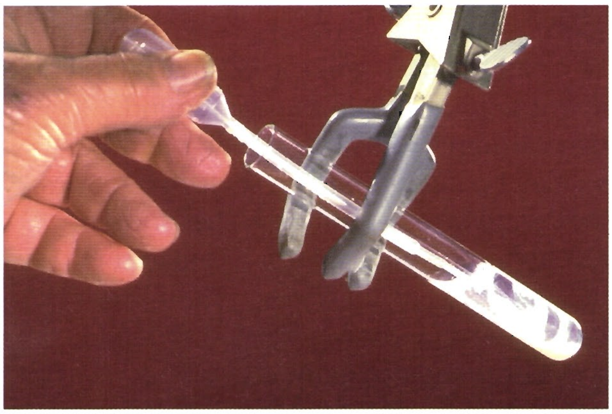


Figure 10.3 The precipitation of silver chloride

Chemists use equations to describe what happens in a **chemical reaction**. The equations save time and space and provide the essential information in an easy-to-read form. The simplest equations are word equations.

The substances that take part in a reaction are called the **reactants**. The substances that form as a result of the chemical reaction are called the **products**. This can be represented by:

reactants → products

In an equation the reactants are written on the left-hand side of the equation and the products are written on the right-hand side. If there are two or more reactants or products in the equation they are linked together by plus (+) signs:

reactant A + reactant B → product C + product D

An arrow points from the reactants to the products. When sodium chloride solution is poured into silver nitrate solution a chemical reaction takes place. It produces a white insoluble solid which is silver chloride. In the chemical reaction between iron and sulfur the iron and the sulfur are the reactants and the compound iron sulfide is the product. The word equation for the reaction is:

iron + sulfur → iron sulfide

1 What is the difference between a product and a reactant in a chemical reaction?

2 Look at the chemical reaction taking place in Figure 10.3.

a) Write down the reactants in this reaction on the left-hand side of a word equation.

b) There are two products of the reaction. One is mentioned in the caption. What is it?

c) What could the other product be?

d) Complete the word equation you began in part **a)**.

Chemical names of compounds

Chemical names can seem complicated but there are rules for how the names are built up. Here are just a few examples.

The first part of the name is usually the name of an element in the compound. The second part of the name usually has part of the name of a second element in the compound.

If the element is not connected to other elements the suffix *-ide* may be added as in iron sulfide. Another example is the chemical name for common salt. This is a compound made from sodium and chlorine and is called sodium chloride.

If more than one atom of an element joins to an atom of the first named element, the prefix *di-* for two or *tri-* for three is added. An example of this is carbon dioxide. The *di-* part of the name tells you that there are two atoms of oxygen joined to a carbon atom and the *-ide* part tells you that there are no other elements in the compound.

If there are two elements joined to the first named element a name may be made up from their two names. For example, sodium hydroxide tells you that sodium is combined with hydrogen and oxygen to make the compound.

The suffix *-ate* is used to indicate that the second named element is also joined to some oxygen atoms. For example, calcium carbonate means that the compound contains calcium, carbon and oxygen.

3 Which elements are present in the following compounds?

a) Calcium oxide
b) Sulfur dioxide
c) Potassium hydroxide
d) Calcium sulfate
e) Copper carbonate

Figure 10.4 The 'limelight man' provided light in theatres before electric light was used. He directed the flame of a mixture of the gases oxygen and hydrogen onto a piece of calcium oxide which produced a powerful white light in the heat.

Table 10.1 Some of the compounds that you may meet in your science course

Compound	Description
calcium oxide	• a white solid used to produce limelight (see Figure 10.4) • commonly called quicklime
carbon dioxide	• a colourless gas produced in respiration
copper oxide	• a black pigment used to colour pottery
sulfur dioxide	• a colourless gas produced when fossil fuels are burnt • produces acid rain
calcium hydroxide	• a white solid used in the treatment of sewage and drinking water • used to make limewater for laboratory tests
potassium hydroxide	• a colourless solid used in soap making • makes an alkaline solution used in laboratories
sodium hydroxide	• a colourless solid used in soap making • makes an alkaline solution used in laboratories
sodium chloride	• a white crystalline solid • also known as common salt
potassium chloride	• a white crystalline solid used in making fertiliser
calcium chloride	• a white solid which absorbs water vapour from the air • used to keep material dry
calcium sulfate  **Figure 10.5** This broken limb is protected by a plaster of Paris case to help it heal.	• a white solid • used to make plaster of Paris
	(continued)

copper sulfate  **Figure 10.6** Copper sulfate crystals	• can form a white powder or bright blue crystals
calcium carbonate  **Figure 10.7** Pinnacles Desert in Australia is a limestone landscape.	• a white solid • a component of snail shells and egg shells present in large amounts in limestone
copper carbonate  **Figure 10.8** The mineral malachite is made from copper carbonate.	• a blue-green solid which can form the mineral called malachite

Mixtures

A mixture is composed of two or more separate substances. The composition of a mixture may vary widely. One mixture of two substances, A and B, might have a large amount of A and a small amount of B. Another mixture might have a small amount of A and a large amount of B.

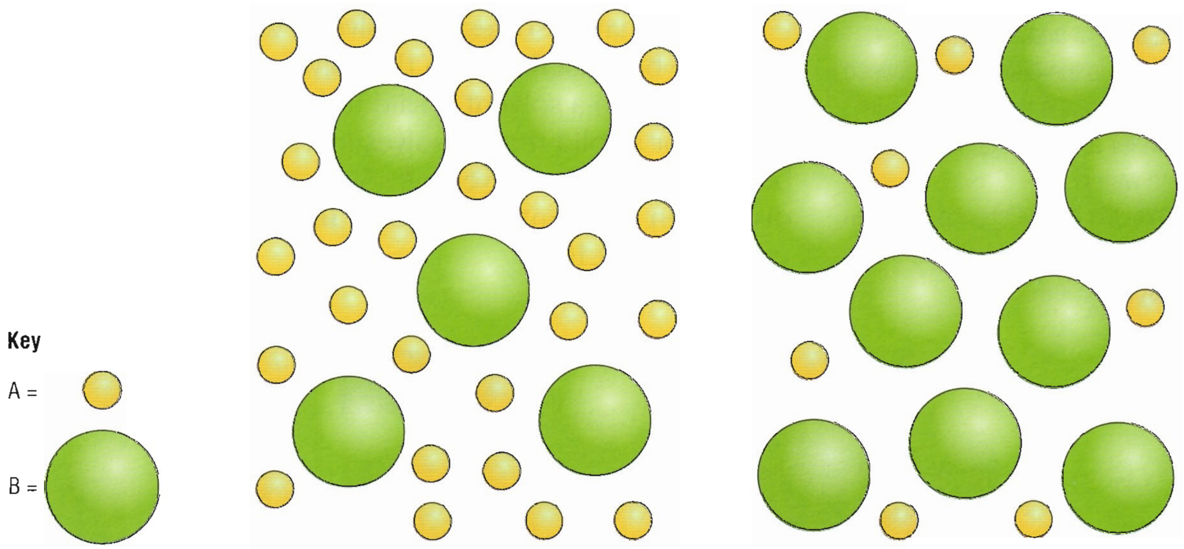


Figure 10.9 Two different mixtures of A and B

Different types of mixtures

There are many different types of mixtures as the following examples show.

Table 10.2 Different types of mixtures with examples

Type of mixture	Examples
solid mixed with a solid	• soil contains clay, silt and sand
solid mixed with a liquid	• clay and water – the clay particles are suspended in the water and make a mixture called a **suspension** • if the solid dissolves a **solution** is made (see page 124)
solid mixed with a gas	• smoke
liquid mixed with a liquid	• milk is made from tiny droplets of oil in water. This type of mixture is called an **emulsion** • some paints are also emulsions
gas mixed with a gas	• air contains nitrogen, oxygen, carbon dioxide and many other gases
liquid mixed with a gas	• mist is tiny droplets of water mixed with air • a suspension of liquid droplets in a gas is called an aerosol
gas mixed with a liquid	• bubbles of a gas trapped in a liquid form foam • foams can be used for shaving products and for giving protection from the Sun

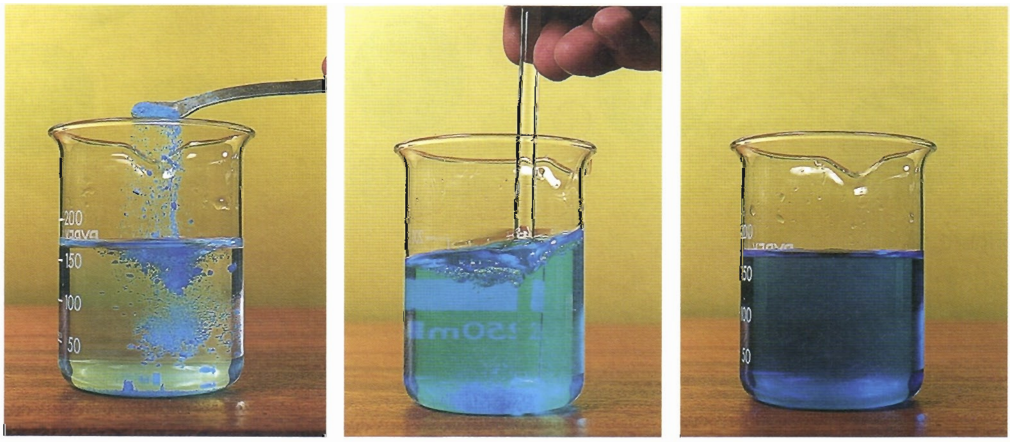
4 What type of mixture is the muddy water in a flood?
5 What type of mixture is a sandstorm?
6 What is the difference between a spray and a foam?
7 What is the difference between a solvent and a solute?
8 What is the difference between a substance that is soluble in water and one that is insoluble in water?
9 What is the difference between an immiscible substance and an emulsion?

Solutions

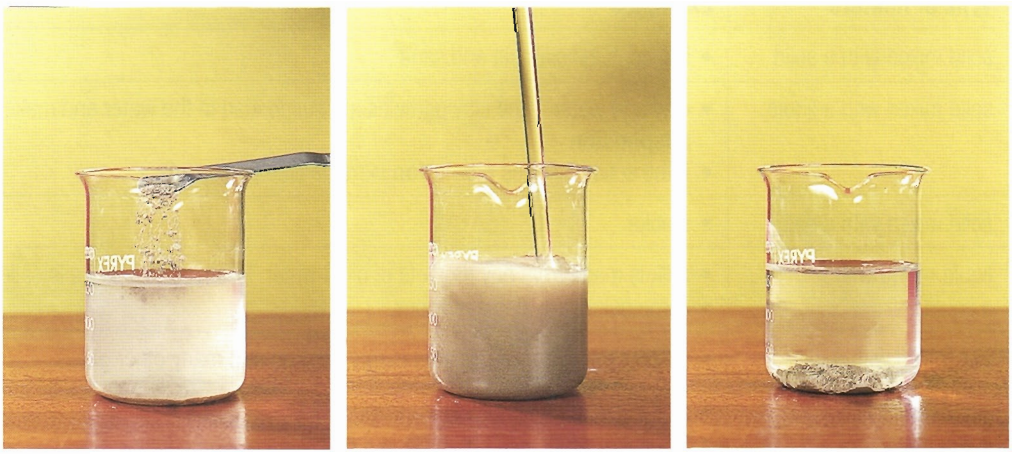
The most common mixture used in chemistry investigations is the solution. A solution is made when a substance, called a **solute**, mixes with a liquid, called a **solvent**, in such a way that the solute can no longer be seen, although if it is coloured it may give its colour to the solution. This type of mixing is called dissolving. The solute may be a solid, a liquid or a gas.

A liquid that dissolves in a solvent, water, for example, is said to be **miscible** with the solvent. A liquid that does not dissolve in a solvent is said to be **immiscible** with it.

A gas or a solid that dissolves in a solvent is said to be **soluble** in that solvent. A solid or gas that does not dissolve in a solvent is said to be **insoluble** in that solvent (see Figure 10.10).



Copper sulfate dissolves in water to form a blue solution.



Clay does not dissolve in water but forms a suspension that settles at the bottom of the liquid after some time and forms a **sediment**.

Figure 10.10 Soluble and insoluble substances

Different solvents

Water has been called the universal solvent because so many different substances dissolve in it. However there are many liquids used as solvents in a wide range of products. Ethanol is used in perfumes, aftershaves and glues. Propanone is used to remove nail varnish and grease. Gloss paint is dissolved in white spirit.

Substances that dissolve in one solvent do not necessarily dissolve in another. Salt dissolves in water but not in ethanol but white sugar dissolves in both.

A solute does not take part in a chemical reaction when it dissolves so it can be recovered by separating it from the solvent.

Separating mixtures

Earlier we saw that iron powder could be separated from sulfur by the use of a magnet because the iron retained its magnetic properties in the mixture. In many chemistry experiments the substances are mixed with water or another solvent and there are a range of processes which can be used to separate them.

Separating an insoluble solid/liquid mixture

In the home, sieves are used to separate insoluble solids, such as peas, from liquids. This is possible because the particle size of the solid is very much larger than that of water. In chemistry, this is not usually the case and other methods are needed.

Large particles

Decanting

Figure 10.11 Decanting a liquid from a jug

Large particles of an insoluble solid in a liquid settle at the bottom of the liquid's container. They form a layer called a sediment. The liquid and solid can be separated by **decanting**. A liquid is decanted by carefully pouring it out of the container without disturbing the sediment at the bottom. At home, some medicines and after-sun lotions form a sediment in the bottom of the bottle and have to be shaken to mix the solid and liquid before being used.

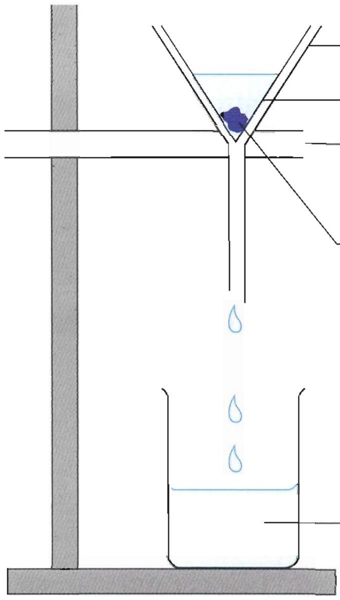


Figure 10.12 Filtration with a filter funnel

Small particles

Filtration

In many laboratory experiments, filtration is carried out by folding a piece of filter paper to make a cone and inserting it into a filter funnel. The funnel is then supported above a collecting vessel and the mixture to be separated is poured into the funnel.

The filter paper is made of a mesh of fibres. It works like a sieve but the holes between the fibres are so small that only liquid can pass through them. The solid particles are left behind on the paper fibres.

A fast filter

A Buchner funnel has holes in it. Filter paper is placed over the holes. The funnel is fastened into the top of a flask which is connected to a suction pump by a rubber tube. The suction pump draws air out of the flask. When the mixture is poured into the funnel and the suction pump is switched on the air pressure inside the flask is reduced. The higher air pressure above the mixture pushes on it and speeds up filtration.

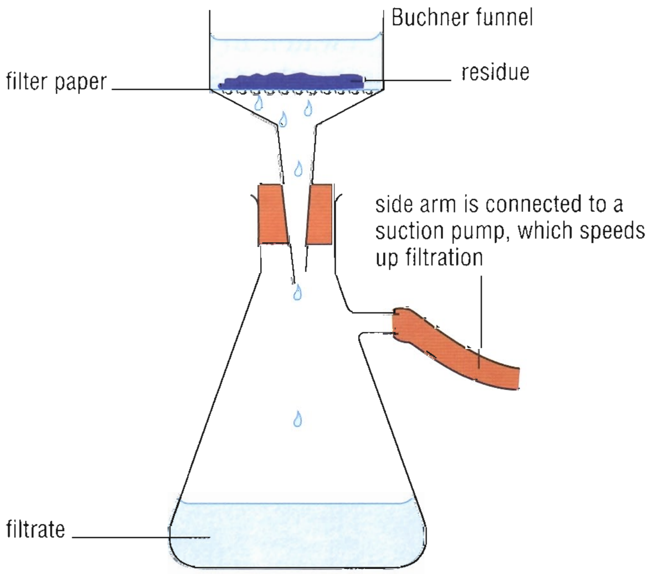


Figure 10.13 Filtration with a Buchner funnel

In both types of filtration the substance left behind on the filter paper is called the **residue** and the liquid that passes through the filter paper is called the **filtrate**.

10 What method of separation would you use to separate:

a) water and fine sand

b) water and gravel

c) water with very tiny particles floating in it?

For each part of the question, explain how the method of separation works.

Centrifuge

Very small insoluble particles in a liquid may be separated from it using a centrifuge. This machine has an electric motor which spins several test tubes mounted on a central shaft. All the test tubes are carefully balanced by having the same amount of liquid poured into them. As the test tubes spin, the small particles are forced to the bottom of the test tubes and form a layer like a sediment. When the test tubes are removed from the centrifuge the liquid can be decanted from them.

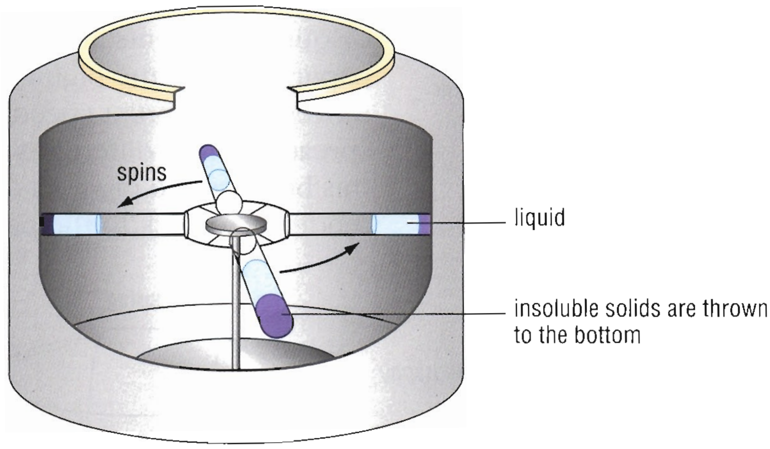


Figure 10.14 A centrifuge

Figure 10.15 Copper sulfate solution being evaporated over a water bath

Separating a solute from a solute/solvent mixture

Separating a solid solute from a solvent

Evaporation

If a solution is heated gently, the solvent evaporates from the surface until only the solid is left. Distilled water is made by boiling and condensing water (see page 129) to remove impurities.

Tap water and seawater may be compared with distilled water by setting up samples of all three types of water and heating them gently until all the liquid has evaporated leaving only the solid content behind.

Crystallisation

A **crystal** is a solid structure with flat sides. Many substances form crystals. One way of making crystals is to make a concentrated solution of a substance and then heat it gently. As the solution warms up the solvent evaporates until the solvent cannot hold any more of the dissolved substance. If the heat is removed at this time and the solution is left to cool the substance forms crystals.

Figure 10.16 Crystals of copper sulfate formed in an evaporating dish

11 The unknown ink mixture used in Figure 10.17 is suspected of containing three different substances. Do the results confirm this?

Separating several different solutes from a solvent – chromatography

A simple **chromatography** experiment can be performed with filter paper, a dropper, ink and water. A drop of ink is placed in the centre of the filter paper, then a drop of water is placed on top of it. The water dissolves the coloured pigments and spreads out through the filter paper, carrying the pigments with it. Each type of pigment moves at a different speed to the others so that they spread out into different regions of the paper. They do this because the pigments vary in their solubility and their tendency to stick to the paper.

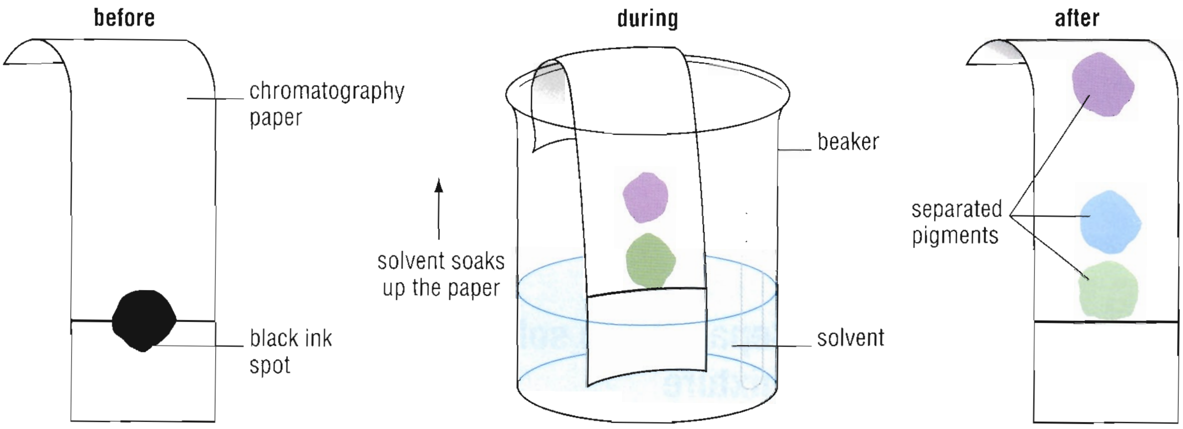


Figure 10.17 Simple paper chromatography

Very soluble pigments which do not tend to stick to the paper move the furthest and pigments which are not very soluble and tend to stick to the paper move the least. When the separation is complete, the paper is dried. The paper with its separate pigments is called a chromatogram. Substances that do not dissolve in water can be separated by chromatography by using other solvents, such as propanone. When one of these solvents is used the chromatography paper is enclosed in a tank.

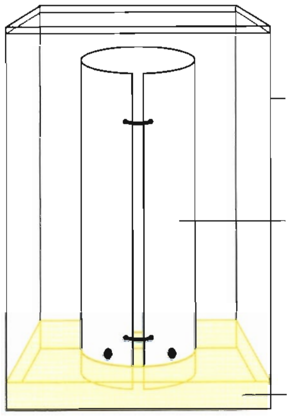


Figure 10.18 A chromatography tank

This makes sure that the solvent vapour does not escape but surrounds the paper keeping it saturated with solvent and helping the substances to separate.

Separating a solvent from a solute/solvent mixture

During evaporation or boiling, the liquid solvent is lost to the air. If the solvent is important it can be separated from the mixture using a process called **distillation**.

Simple distillation

In a very simple form of distillation, the solution is placed in a test tube which is set up as shown in Figure 10.19.

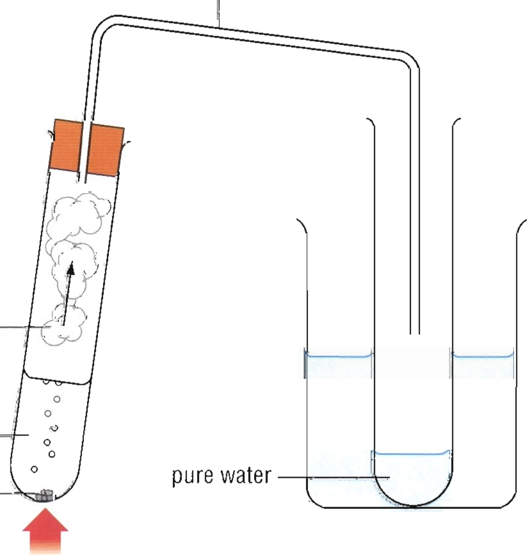


Figure 10.19 Simple distillation

The antibumping granules provide many places where bubbles of gas may form as the water boils. The bubbles are small and rise steadily to the surface of the liquid where they burst. Without the granules, fewer but larger bubbles form. These rise and burst with such force that they shake the test tube.

As the water boils the steam moves along the delivery tube. At first the tube is cool enough to make some of the steam condense but as more steam passes along the tube it becomes hotter and no more condensation takes place.

The cold water in the beaker keeps the walls of the second test tube cool so that most of the steam condenses there and water collects at the bottom of the tube. The solid solute remains in the first tube. (Liquid and gas solutes are separated by fractional distillation.) The purity of the water can be checked by boiling it and recording its boiling point with a thermometer.

Distillation with a Liebig condenser

The Liebig condenser is a glass tube surrounded by a glass chamber called a water jacket. During the distillation process, water is allowed to flow from the cold tap through the water jacket and down the sink. The water takes away the heat from the hot vapour in the tube of the condenser and causes it to condense. The liquid formed by the condensed vapour is called the **distillate**. It flows down the tube and drips into the collection flask.

12 Why is the Liebig condenser more efficient than the simple distillation apparatus?

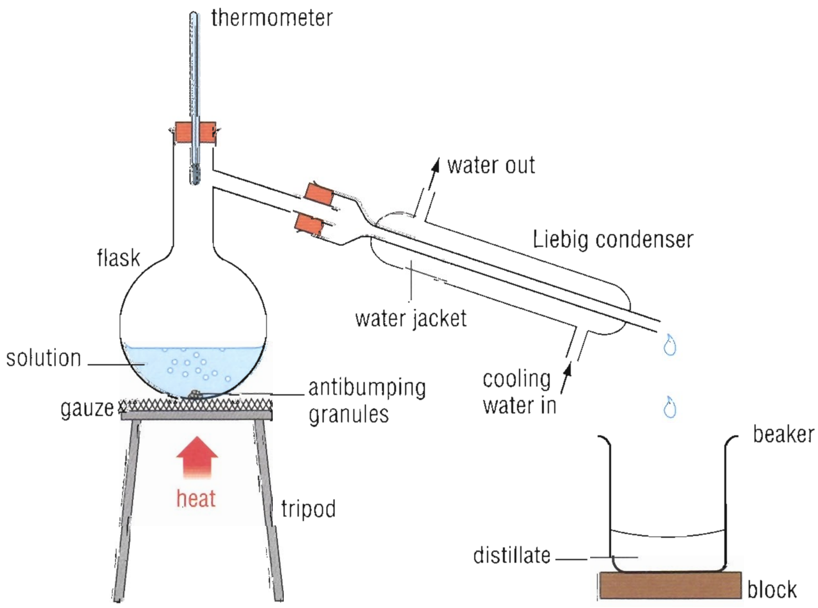


Figure 10.20 Distillation with a Liebig condenser

Separating two immiscible liquids

When two immiscible liquids are mixed together and then left to stand, they eventually form layers. This can be seen when oil and vinegar are mixed together to form salad dressing.

Figure 10.21 Salad dressing mixture after shaking (left) and after standing for 10 minutes (right)

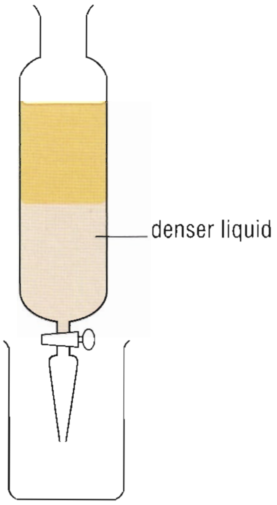


Figure 10.22 A separating funnel

The less dense liquid forms a layer above the more dense liquid. A separating funnel (see Figure 10.22) can be used to separate them. The tap is opened to let the liquid in the lower layer flow away into a beaker. A second beaker can be used to collect the liquid from the upper layer.

SUMMARY

- Elements in a mixture keep their own properties (*see page 118*).
- Elements in a compound lose their own properties (*see page 119*).
- Compounds are produced by chemical reactions (*see page 119*).
- Chemical reactions can be described by word equations (*see page 119*).
- The names of elements are used in making the names of chemical compounds (*see page 120*).
- Oxides, hydroxides, chlorides, sulfates and carbonates are all chemical compounds (*see pages 121–122*).
- There is a wide range of mixtures in which solids, liquids and gases combine together (*see page 123*).
- A solution is composed of a solute and a solvent (*see page 124*).
- There are many solvents. Substances that dissolve in one solvent may not dissolve in another (*see page 125*).
- Solids may be separated from liquids by decanting, filtration or by using a centrifuge (*see pages 125–127*).

- A solid solute may be separated from a solvent by evaporation, crystallisation or chromatography (*see pages 127–128*).
- A solvent may be separated from a solid solute by distillation (*see pages 129–130*).
- Two immiscible liquids may be separated by using a separating funnel (*see page 131*).

End of chapter question

How would you separate the different parts of a mixture of sand and salty water? List the items that you would use for each process.

11 Metals and non-metals

- Metals and non-metals in the periodic table
- Physical properties of metals and non-metals
- Chemical properties of metals and non-metals
- Reactions between metals and non-metals
- Reactions between oxygen and metals and non-metals

Almost everyone knows from an early age what a metal is. It is shiny, hard and feels cool to the touch. Chemists divide the elements into metals and non-metals and while we know what a metal is, most people are unsure about non-metals. Non-metal elements are not as striking in appearance as metals and some are colourless but they form most of the matter in the Earth's crust, the oceans, the atmosphere and even living things.

Figure 11.1 Most of the features of our world are composed of non-metals.

Metals and non-metals in the periodic table

1 How many of the first twenty elements you learnt about in Chapter 9 are:

a) metals

b) non-metals?

In Chapter 9 the periodic table was introduced and you were set the challenge of learning about the first twenty elements in it. Here is the periodic table again but this time we are going to look at the distribution of the metals and non-metals in it.

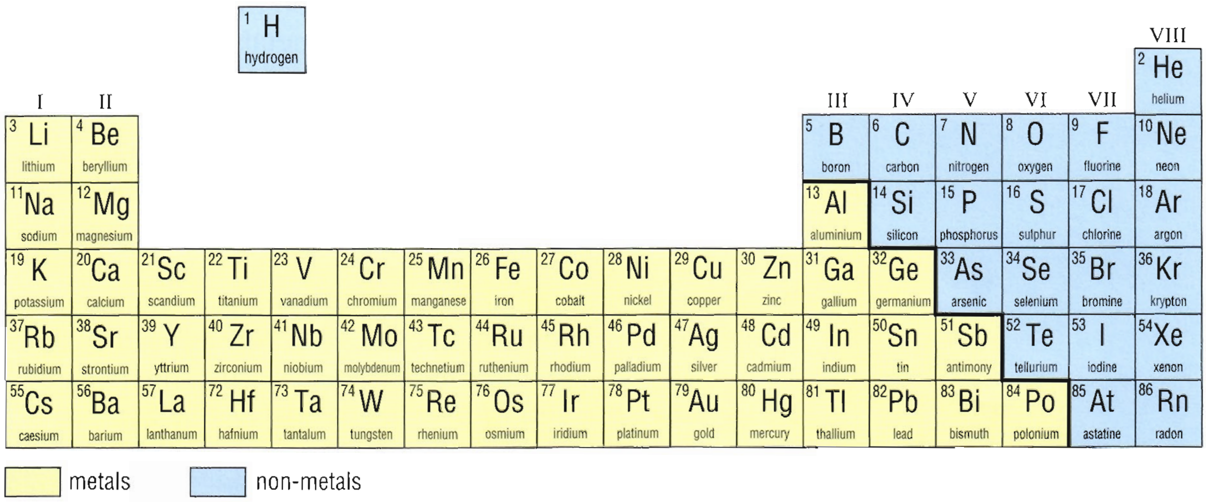


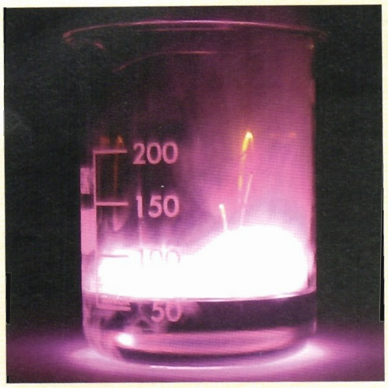
Figure 11.2 Part of the periodic table showing the positions of the metals and non-metals

The uses and properties of metals

Most of the metals that we use are not in their pure elemental form. We use metals mostly in alloys or in compounds with other metals and with non-metals. Table 11.1 is a survey of just ten metals to show their range of features and uses and some of their physical properties.

Table 11.1 Some notable features and uses of ten common metals

Metal	Notable features	Uses
sodium  **Figure 11.3** Electricity heats the sodium until it changes into a gas called a vapour and gives out an orange-yellow glow.	• can be easily cut up with a knife • floats and burns on water	• orange street lamps
magnesium  **Figure 11.4** This magnesium flare is being used in a rescue at sea.	• strips and powder catch fire easily	• flares for the rescue of shipwrecked people • camera flashbulbs
aluminium  **Figure 11.5** The bodies of aeroplanes are made of aluminium because they are light-weight and do not corrode.	• has a low **density** which makes it light-weight • does not corrode in air	• aircraft • power cables *(continued)*

Metal	Notable features	Uses
potassium  **Figure 11.6** This is what happens when a piece of potassium the size of a pea is dropped into water.	• can be easily cut up with a knife • explodes with water	• dyes, inks • fertiliser • weed killer
calcium  **Figure 11.7** Calcium is present in the stones of the older buildings and the concrete blocks of the new buildings.	• some effort is needed to cut it up with a knife • very reactive and present in many compounds	• huge number of uses including cement and concrete, cosmetics, toothpaste, insecticides, paints and cheese making
iron  **Figure 11.8** Steal car bodies at the start of a production line in a car factory	• a hard substance that can be shaped to make a wide variety of strong, hard objects • can decompose into flakes of rust (see page 151)	• wrought iron was used for making swords, horseshoes and nails in the past • cast iron used to make utility-hole covers • combined with carbon to make steel cutlery and car bodies

Metal	Notable features	Uses
copper  **Figure 11.9** A copper lightning conductor protects a tower on a building.	• a red-orange metal which is soft enough to pull easily into wires or press into sheets • very good conductor of heat	• wires in electrical circuits • lightning conductors • hot water cylinders • copper-bottomed pans
zinc  **Figure 11.10** Sheets of metal are coated with zinc in this iron and steel works in Russia to stop it rusting.	• a brittle blue-white metal which does not corrode in the air	• rust prevention (see page 152) • used in making some cells to generate electricity
silver  **Figure 11.11** Silver is used to make a range of highly decorated objects.	• a shiny white metal that is soft enough to be made into complicated shapes by pulling into wires and pressing into sheets	• jewellery, coins, ornaments • mirrors *(continued)*

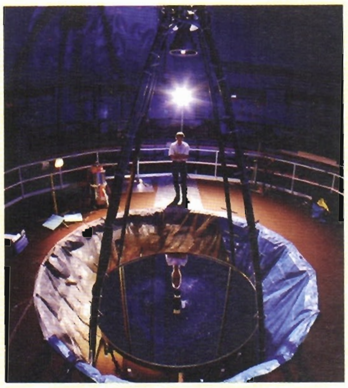
Metal	Notable features	Uses
mercury  **Figure 11.12** Mercury is spun in a bowl at high speed to make a thin, highly reflective layer for use in liquid mirror telescopes.	• a shiny silver liquid	• thermometers • fluorescent lamps • tooth fillings • liquid mirror telescopes

Table 11.2 Some physical properties of ten common metals

Element	Density/g/cm^3	Melting point/°C	Boiling point/°C	Electrical conductor
sodium	0.97	98	883	yes
magnesium	1.7	650	1091	yes
aluminium	2.7	660	2519	yes
potassium	0.89	63	759	yes
calcium	1.6	842	1484	yes
iron	7.9	1538	2862	yes
copper	8.9	1085	2562	yes
zinc	7.1	420	907	yes
silver	10.5	962	2162	yes
mercury	13.5	−39	357	yes

The uses and properties of non-metals

Most of the non-metals that we use are not in their pure elemental form. We use them in compounds with metals and with other non-metals. Table 11.3 shows a survey of just seven non-metals to show their range of features and uses and some of their physical properties.

Table 11.3 Some notable features and uses of seven common non-metals

Non-metal	Notable features	Uses
hydrogen  **Figure 11.13** Hydrogen burning in air	• a colourless, odourless gas • can burn in air but a certain air/hydrogen mixture explodes	• used in making products from oil
helium  **Figure 11.14** These large helium balloons can lift people high into the air.	• a colourless, odourless gas • less dense (and therefore lighter) than air • does not burn in air	• party balloons, airships • provides low temperatures for super-conducting magnets in MRI scanners *(continued)*

<table>
<tr><th>Non-metal</th><th>Notable features</th><th>Uses</th></tr>
<tr><td>carbon

Figure 11.15a This diamond-tipped drill can bore a hole in rock.

Figure 11.15b Carbon in pencil leads</td><td>two main forms:
• diamond – hard, transparent crystal
• graphite – a grey, shiny, slippery solid which conducts electricity</td><td>• diamond – jewellery, saws, drills and certain types of scalpel
• graphite – used with clay to make pencil leads, lubricants for machinery and in some kinds of batteries and electric motors</td></tr>
<tr><td>nitrogen


Figure 11.16 The low temperature of liquid nitrogen has a wide range of uses from storing biological material such as cells, to providing cooling in some large computer systems.</td><td>• a colourless, odourless gas
• does not allow things to burn in it
• slows down chemical reactions which cause decay</td><td>• food storage bags
• aircraft tyres
• to provide a low temperature for the storage of blood</td></tr>
</table>

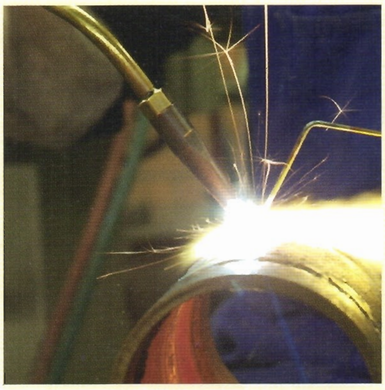
Non-metal	Notable features	Uses
oxygen  **Figure 11.17** A torch burning acetylene in oxygen gas is being used to weld two metals together.	• a colourless, odourless gas • supports burning • is needed for respiration	• life support systems in hospital to help breathing • in industry for welding and cutting metals
sulfur  **Figure 11.18** Sulfur burns with a blue flame.	• yellow, brittle solid • does not dissolve in water • burns in air to produce sulfur dioxide gas	• to make rubber harder for use as tyres • as a fungicide to protect crops
bromine  **Figure 11.19** Fumes rise from the surface of liquid bromine	• a red-brown liquid which is slightly transparent • produces red-brown toxic fumes with an unpleasant smell • soluble in water • present in seawater from which it is extracted	• flame retardants • dyes • disinfectants

Table 11.4 Some physical properties of seven common non-metals

Element	Density/g/cm^3	Melting point /°C	Boiling point/°C	Electrical conductor
hydrogen	0.000 09	–259	–253	no
helium	0.00017	–272	–269	no
carbon (graphite)	2.5	3642	sublimes	yes
nitrogen	0.0012	–210	–196	no
oxygen	0.0013	–219	–183	no
sulfur	2.0	115	445	no
bromine	3.1	–7	59	no

2 What feature of magnesium makes it suitable for making flares?

3 Why do the notable features of aluminium make it suitable for making aircraft and power cables?

4 Why is copper particularly useful in electrical circuits?

5 Why is helium used in airships?

6 Why is graphite used as a lubricant?

7 Why is oxygen used in life support systems in hospitals?

8 a) Use the data on the physical properties of the metals and non-metals in Tables 11.2 and 11.4 to arrange the metals and non-metals in order of their densities, starting with the most dense.

b) What general conclusions can you draw from your list?

c) What exceptions can you find to your general conclusions?

d) Gold is a metal with a density of 19.3 g/cm^3. How does this information fit with your general conclusion?

e) Iodine is a non-metal with a density 4.9 g/cm^3. How does this information fit with your general conclusion?

9 a) Use the data on the physical properties of the metals and non-metals in Tables 11.2 and 11.4 to arrange the metals and non-metals in order of their melting points, starting with the element that has the highest melting point.

b) What general conclusions can you draw from your list?

c) What exceptions can you find to your general conclusions?

d) Silicon is a non-metal with a melting point of 1414 °C. How does this information fit with your general conclusion?

e) Lead is a metal with a melting point of 327.5 °C. How does this information fit with your general conclusion?

10 Can the property of electrical conductance be used to distinguish metals from non-metals? Explain your answer.

From surveys like the ones presented in the previous pages a table comparing the properties of metals and non-metals can be produced. Table 11.5 shows this.

11 How could you use the particle theory to explain why metals generally have a greater density than non-metals?

Table 11.5 Physical properties of metals and non-metals

Property	Metal	Non-metal
state at room temperature	solid (one is a liquid)	solid, liquid or gas
density	generally high	generally low
surface	shiny	dull
melting point	generally high	generally low
boiling point	generally high	generally low
effect of hammering	shaped without breaking	breaks easily
magnetic	a few examples	no examples
conduction of heat	good	very poor
conduction of electricity	good	very poor (one conductor)

Chemical properties of metals and non-metals

So far in this chapter the physical properties of metals and non-metals have been explored. Physical properties can be examined simply by observing an element, perhaps heating it up or cooling it down or applying a force to it to see if it bends or snaps.

Each element also has chemical properties. A chemical property of a substance reveals itself when a chemical reaction takes place. When this happens the element changes in some way. An example of this was shown at the beginning of Chapter 10 (see page 119). The iron and sulfur were present as elements but after the chemical reaction they formed the compound iron sulfide.

Two properties which are investigated by carrying out chemical reactions are how metals and non-metals react together and how they react with oxygen.

Metals reacting with non-metals

Some metals and non-metals react together to produce compounds of the two elements. Some examples are shown on pages 144 and 145.

Figure 11.20 Sodium burns brightly in chlorine to form common salt.

If a burning piece of sodium is placed in a container of chlorine gas in a fume cupboard the two elements react and produce a great deal of light as they combine to make the white solid sodium chloride.

The word equation for this reaction is:

sodium + chlorine → sodium chloride

If zinc or copper is heated with sulfur the metal sulfide is formed. The word equations for these reactions are:

zinc + sulfur → zinc sulfide

copper + sulfur → copper sulfide

Reaction with oxygen

Oxygen is a non-metal and reacts with many metals and non-metals to form oxides. The reaction of metals and non-metals with oxygen forms a separate property to the general one about the reaction between metals with non-metals such as chlorine and sulfur.

Reaction of metals with oxygen

If a metal takes part in a chemical reaction with oxygen, a metal oxide is formed. Here are some examples.

When sodium is burnt in oxygen a chemical reaction takes place which produces the white powder sodium oxide.

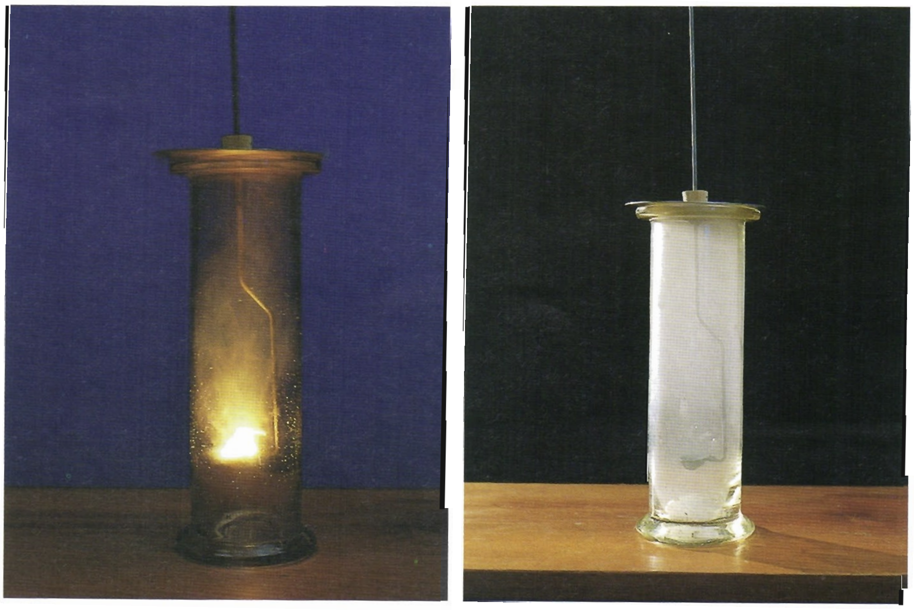


Figure 11.21 Sodium burning in a gas jar of oxygen (left). Sodium oxide powder is produced as the chemical reaction takes place (right).

12 What is the word equation for the reaction between calcium and oxygen?

13 Which is true? All alkalis are bases or all bases are alkalis.

14 a) What is the word equation for the reaction between copper oxide and sulfuric acid?

b) What colour change is seen? Compare the copper compounds at the beginning and end of the reaction.

When calcium is burnt in oxygen it burns with a bright red flame and produces the white powder calcium oxide.

Magnesium ribbon easily catches fire if it is held in a Bunsen burner flame. It burns with a brilliant white light if plunged into a gas jar of oxygen. Magnesium oxide (a white powder) is produced, which dissolves in water to make an alkaline solution with a **pH** of 8.

If copper is heated strongly in air it reacts with the oxygen in it and forms the black powder copper oxide.

Metals oxides are called **bases**. A base is a substance which takes part in a chemical reaction with an acid and neutralises it. Some metal oxides, such as sodium oxide and calcium oxide, are bases that dissolve in water and form **alkalis**. Other metal oxides, such as copper oxide, do not dissolve in water but they do react with acids and neutralise them. For example, when copper oxide reacts with sulfuric acid, copper sulfate and water are produced.

Reaction of non-metals with oxygen

If a non-metal takes part in a chemical reaction with oxygen it also forms an oxide. Most oxides of non-metals are soluble. When they dissolve in water they form acids. Sulfur is a non-metallic element with a yellow crystalline form. If it is heated in air it burns and combines with oxygen to form sulfur dioxide, which is soluble in water. This reaction occurs between sulfur dioxide and water:

sulfur dioxide + water → sulfurous acid

The compound sulfurous acid has one fewer oxygen atom in its structure than sulfuric acid.

When carbon powder is heated in air it glows red. If it is plunged into a gas jar of oxygen it becomes bright red. Carbon combines with oxygen to form carbon dioxide, which dissolves in water to form an acidic solution with a pH of 5.

15 How may the reaction with oxygen be used to distinguish a metal from a non-metal?

SUMMARY

- Metals and non-metals are found in specific areas of the periodic table (*see page 134*).
- The physical properties of metals and non-metals can be compared (*see pages 134–142*).
- Chemical properties are different from physical properties (*see page 143*).
- Some chemical reactions take place between metals and non-metals (*see page 143*).
- The way metals and non-metals react with oxygen can be compared (*see pages 144–145*).

End of chapter question

1 Over 500 planets have been discovered outside the Solar System. They orbit stars at different distances. Some are in a close orbit and are very hot while others are at greater distances and much cooler.

a) In what form (solid, liquid or gas) would you predict the following elements to be on a planet if its temperature was 1000 °C: sodium, magnesium, iron, copper, zinc, silver, carbon, sulfur?

b) In what form (solid, liquid or gas) would you predict the following elements to be on a planet if its temperature was –200 °C: nitrogen, oxygen, bromine, helium, mercury, copper?

12 Chemistry in everyday life

- Respiration and combustion
- Burning and explosions
- Oxidation
- Oxygen and food
- Rusting
- Reactions between other metals and the air

We see plants and animals around us so it is not hard to think about biology in our everyday lives. We see things moving about due to the action of forces and sense different forms of energy such as light, sound and heat so, again, it is not hard to think about physics in everyday life – but what about chemistry? Physical changes such as melting, freezing, boiling, condensing and dissolving are easy to see but what about chemical reactions?

Respiration

1 a) What chemical reaction is taking place in a green plant in sunlight?
b) What are the reactants in this reaction?
c) What are the products?

We must know more about what we are looking at before we can think about the chemical reactions taking place. For example, look at the people around you and think about the chemical reaction that is taking place inside them that is keeping them alive. The chemical reaction is respiration and the word equation for it is:

glucose + oxygen → carbon dioxide + water

In this process energy is released from glucose molecules to provide the energy for all the life processes taking place in the body.

Combustion

You only need to look along a busy city street to see evidence of another chemical reaction that produces useful energy. This reaction is called **combustion** and

occurs in the petrol and diesel engines of the vehicles moving along. Combustion is a chemical reaction in which a substance, usually a fuel, takes part in a fast reaction with oxygen to release heat energy. The word equation for combustion is:

fuel + oxygen → carbon dioxide + water

Figure 12.1 Respiration and combustion are taking place here to keep the people alive and move the vehicles.

Burning

If a flame develops during combustion the reaction is then called burning. During burning, energy is given out as heat, light and sound.

> **For discussion**
>
> **The kitchen is the room in the home which is most like a chemical laboratory. What physical changes take place in the kitchen? What chemical change takes place in a mixture when vinegar is added to it? What chemical change takes place when yeast is used to make dough? If gas is used in the oven what word equation describes the burning of gas to produce heat?**

Figure 12.2 The burning candles in these lanterns produce an unusual lighting effect on the water.

2 A teacher sets up a candle in a tin and places some cornflour powder next to it in the tin. She lights the candle and puts a lid on the tin and then blows into it through a tube to make the cornflour form a dust around the candle.

a) What do you think will be heard?

b) What do you think will be seen?

c) Why have these changes taken place?

Explosions caused by dust

Very occasionally there may be a news story about an explosion in a coal mine or in a flour mill. Explosions in these places can be caused by the coal and flour themselves and not explosives such as dynamite. The explosion is due to the materials forming a dust in the air. If a piece of coal is heated, it produces a flame and burns steadily in air. If coal dust is heated, it explodes. The reason for this difference is the surface area of coal in contact with the air. When a piece of coal is ground into dust it has a much larger surface area in contact with the oxygen in the air. This means that once the coal dust is hot it can react very quickly. The heat produced by this fast reaction causes the air to expand rapidly and push on everything around it with great force.

Figure 12.3 A coal mine where dust-reduction methods are used

Reactions with oxygen

A chemical reaction in which oxygen combines with a substance is called an **oxidation** reaction.

Oxygen and food

Some foods contain fats and oils. If they are left out in the air for a few days they may start to smell unpleasant. This is due to the oxidation reaction which takes place between the fats and oils and the oxygen in the air. It results in the food becoming rancid and inedible.

Chemicals have been developed to slow down the oxidation of fats and oils in air. They are called antioxidants.

Many foods, such as corn chips, are further protected from oxidation by the gas in their unopened bags. It is nitrogen. As oxygen is not present in the bags, oxidation cannot take place. Once the bags are open the antioxidants in the food prevent the food from going rancid.

3 Have a look at the ingredients listed on the packaging of a range of prepared foods.

a) How many of the foods have antioxidants added to prevent the food going rancid?

b) What percentage of the foods you examined have antioxidants in them?

Figure 12.4 Citrus fruits like lemons contain an antioxidant.

Hand warmers

People who spend time in cold conditions sometimes use hand warmers to keep them comfortable. In one type of hand warmer iron is enclosed in a pair of bags which are sealed in a packet to keep out the air. When they are needed the packet is opened and air passes through the

4 Imagine you are stranded in very cold conditions but you know you will be rescued within 12 hours. How would you use two pairs of hand warmers to help keep you alive?

walls of the bags. The oxygen in the air reacts with the iron to produce iron oxide. During this reaction heat is given out and is spread out by other substances in the bag so that the whole hand holding the bag becomes warm. The hand warmer gives out heat for up to 12 hours.

Figure 12.5 Handwarmers are stored in sealed packages until they are needed to provide heat to the body.

5 When a piece of iron rusts, would you expect its mass to increase or decrease? Explain your answer.

Figure 12.6 A rusted iron gate post

Rusting

Rusting is a slow reaction which takes place between iron, oxygen and water. This reaction can be written as the word equation:

iron + oxygen + water → rust

The chemical name for rust is hydrated iron oxide.

When water vapour from the air condenses on iron or steel it forms a film on the surface of the metal. Oxygen dissolves in the water and reacts with the metal to form iron oxide. This forms brown flakes of rust which break off from the surface and expose more metal to the oxygen dissolved in the water. The iron or steel continues to produce rust until it has completely corroded.

Steel is used for making girders that support bridges and for making many parts of cars. If the steel is not protected it soon begins to rust. This weakens the metal. It makes bridges unsafe. It makes holes in car bodies and weakens the joints that hold the cars together, making them unsafe for use.

Steel is a compound of iron and carbon. The iron in this compound rusts when exposed to damp air.

Factors that speed up rusting

Like most chemical reactions, rusting speeds up if the reactants are warmed. The presence of salt in the water on the metal also speeds up rusting.

Rust prevention

Rust can be prevented by keeping oxygen and water away from the iron or steel surface. This can be done by painting the surface or covering it in oil. However, if the paint becomes chipped or the oil is allowed to dry up, rust can begin to form.

Steel can also be protected by covering the surface with chromium in a process called chromium plating. Steel used for canning foods is coated in a thin layer of tin.

The steel used for girders to build office blocks and bridges is coated in zinc in a process called zinc plating or galvanising.

Steel can also be prevented from rusting by mixing it with nickel and chromium to make the metal alloy called stainless steel. This is used for cutlery and kitchen sinks.

Figure 12.7 A bicycle with a frame which is resistant to rusting.

Other metals and the air

When aluminium or zinc is exposed to the air, the metal on its surface reacts with oxygen in the air and forms oxides. These oxides do not flake like rust but form a protective surface on the metal.

6 In countries where ice forms on the roads in winter, salt may be used to lower the freezing point of the ice and make it melt.

Figure 12.8 Salt is being spread from the back of a truck to treat an icy road.

A car is driven through streets treated with salt and then parked in a warm garage.

a) How will the rate of rusting compare with a car that has not been driven in the streets treated with salt but left parked outside? Explain your answer.

b) What advice would you give to the driver of the first car to slow down rusting?

7 Many tall buildings have a framework made of steel girders on which walls of brick and glass are built. If the steel was unprotected what would you expect to happen in time? Explain your answer.

8 How do you think that the bicycle in Figure 12.7 has been designed so that metal corrosion will not occur?

Zinc is used to protect iron because it is more reactive with oxygen than iron. Even if the zinc coating on galvanised iron or steel is chipped, the oxygen still reacts with the zinc instead of the exposed iron and rusting is prevented.

A black coating forms on the surface of silver exposed to the air. When this happens the silver is said to be tarnished. The tarnish can be removed by polishing.

The surface of bronze, which is an alloy of tin and copper, develops a thin green film over a long time. This coating is called patina.

Copper is used as a roofing material. Over time its surface reacts with air to form a green coating called verdigris. This substance contains copper carbonate.

Figure 12.9 A bronze statue with patina

Figure 12.10 This copper roof is covered in verdigris

◆ SUMMARY ◆

- Respiration, combustion and burning are common reactions (*see pages 147–148*).
- Certain types of dust can cause explosions (*see page 149*).
- A chemical reaction in which oxygen combines with a substance is called an oxidation reaction (*see page 150*).
- Chemical reactions between oxygen and the fats and oils in food make the food go bad (*see page 150*).
- The reaction between iron and oxygen can produce heat (*see page 150*).
- Rusting is a slow reaction that takes place between iron, oxygen and water (*see page 151*).
- Rust weakens iron and steel (*see page 151*).
- Warmth and salt water speed up rusting (*see page 152*).
- Rust can be prevented by keeping oxygen away from iron and steel (*see page 152*).
- Coatings form on some metals when they are exposed to the air (*see pages 152–153*).

End of chapter questions

1 Which of the everyday reactions in this chapter do you think are:

a) useful

b) not useful?

2 Anita and Arif have identical new bicycles. Anita lives in a dry, cool grassland area and Arif lives in a warm, wet region on the coast. Which bicycle may show signs of rusting first? Explain your answer.

PHYSICS

13 Speed

- Speed records
- Measuring speed
- The distance/time graph
- Velocity

Figure 13.1 How do you measure the runners' speeds?

A few moments after the finish of this race the times of the runners will be flashed up on a score board. If the race was over 100 metres, or any other distance, you may think that the **speed** that a runner ran the entire distance could be worked out using the time. However you would be wrong.

The runners were stationary when the starter gun was fired so they began to run increasingly faster, or accelerate, to get moving.

They may have run steadily for most of the race and then accelerated as much as they could for the final sprint to the finish. Speed is a measure of the distance covered by an object in a certain time.

Speed records

People trying to beat the land speed record must drive their vehicle at full speed between two markers.

Figure 13.2 Breaking the land speed record in 1997

Table 13.1 shows some land speed records from the end of the 20th century. You could check on the internet to see if the 1997 record has been broken.

Table 13.1 Land speed records

Date	Speed/km/h	Driver	Vehicle
15/10/97	1227.99	Andy Green	Thrust SSC
4/10/83	1013.47	Richard Noble	Thrust 2
23/10/70	995.85	Gary Gabelick	The Blue Flame
15/11/65	960.96	Craig Breedlove	Spirit of America
7/11/65	922.48	Art Arfan	Green Monster

1 For how long did Art Arfan's record stand?
2 How much faster than Spirit of America was The Blue Flame?
3 By how much did the land speed record rise between 1965 and 1997?

Measuring speed

The speedometer

The speedometer in a vehicle is connected by a cable to a shaft which turns the wheels. There is a wire in the cable which is connected to the shaft by gear wheels. When the shaft turns, the wire in the cable turns too. At the other

end of the wire is a magnet. It spins round when the vehicle's wheels turn. The magnet is surrounded by a circular metal cup which is affected by the magnetic field generated by the spinning magnet. The cup is made to turn, the turning effect increasing as the speed of the spinning magnet (and the moving vehicle) increases. The cup is connected to a spring and a pointer. The spring prevents the cup spinning but allows it to turn further as the vehicle's speed increases. The pointer turns with the cup and moves across the scale of the speedometer dial.

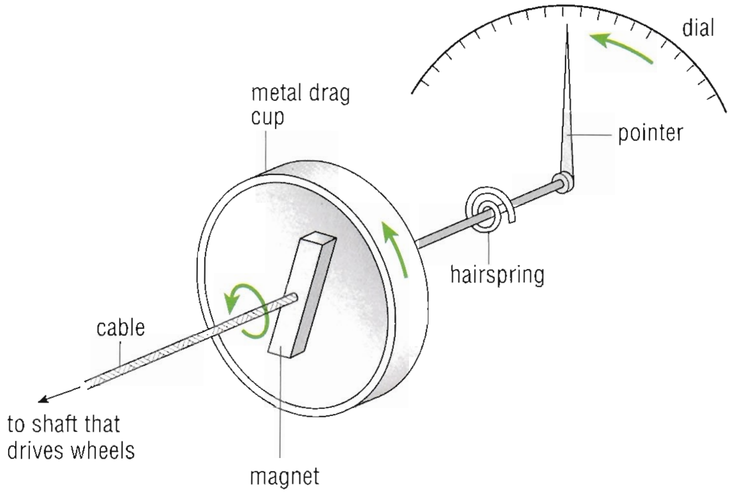


Figure 13.3 A speedometer

The speed trap gun

The speed trap gun is a radar gun. When the gun is fired at an approaching vehicle a beam of radio waves travels to it through the air. This is reflected off the front of the vehicle and returns to a receiver on the gun. A computer in the gun compares the time difference between sending the beam and receiving it back from the vehicle and calculates the vehicle's speed.

The stop watch

For many years, the stop watch was used to find the speed of a moving object in the following way. The stop watch was started as the object passed the start line and was stopped when the object passed the finish line. The distance travelled from the start line to the finish line was measured and divided by the time measured by the stop watch. This gives the speed of the object.

4 Two people timed an object with a stop watch. They each got a slightly different result. How could this be?

5 Which is more reliable – using a manual stop watch or using light gates? Explain your answer.

Light gates

In a light gate a beam of light shines onto a light-sensitive switch. When the beam of the light gate used at the start of a speed test is broken by an object passing through it, the switch starts an electronic stop watch. When the beam of the light gate used at the finish of the speed test is broken by the object passing through it, it causes the stop watch to be stopped. The speed of the object is then found by dividing the distance between the light gates by the time as measured by the electronic stop watch.

Distance/time graphs

The distance travelled by an object over a period of time can be plotted on a graph called a **distance/time graph**. The distance covered by the object is recorded on the vertical axis and the time taken for the object to cover the distance is recorded on the horizontal axis.

When a distance/time graph is complete it can be used to study the speed of an object over different time periods of its journey.

Figure 13.4 shows the distance/time graph for an object which moved at a steady speed (line A), then stopped and remained stationary (line B). If the object had been travelling at a greater speed, line A would be steeper. If the object had been travelling at a lesser speed, line A would be less steep.

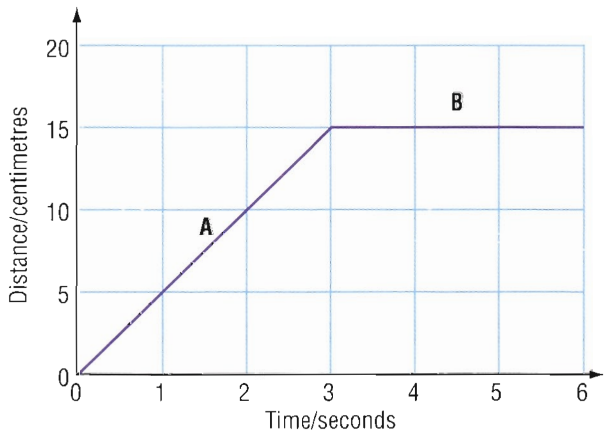


Figure 13.4 A distance/time graph

The speed of an object, that is how far the object moves in a certain time, can be calculated from the distance/time graph. For example, during the time it was moving the object in Figure 13.4 moved at 5 cm/s.

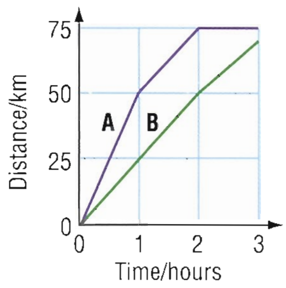


Figure 13.5

6 Figure 13.5 shows the distance/time graph for two trucks, A and B, on an expedition across the Mongolian desert.

a) i) How far did truck A move in the first hour of its journey?

ii) What was its speed during this time?

b) How did the speed of truck A change in the second hour of its journey?

c) Was truck B moving faster or slower than truck A in the first hour of its journey?

d) What do you think might have happened to truck A in the third hour of the journey?

Velocity

When something moves it goes in a particular direction. An aeroplane, for example, may move at 900 km/h in a direction due north. When the speed and the direction of movement are given together this is called the **velocity**.

SUMMARY

- Speed is a measure of the distance covered by an object in a certain time (*see page 156*).
- Speed can be measured using a speedometer or a speed trap gun (*see pages 157–158*).
- To calculate the speed of an object you need to know the distance travelled and the time it took. The time can be measured using a stop watch or light gates (*see pages 158–159*).
- A distance/time graph shows the distance travelled by an object over a period of time (*see page 159*).
- The velocity of an object is its speed and its direction of movement (*see this page*).

End of chapter questions

1 A group of students investigated the movement of a model car. They set up a ramp at a height of 6 cm and let the car roll down it and across the floor (see Figure 13.6).

They measured the distance travelled by the car across the floor after it left the ramp. The experiment was repeated three more times with the ramp set at a height of 6 cm; then the ramp was reset at a different height and more of the car's movements were recorded. Table 13.2 shows the results of the investigation.

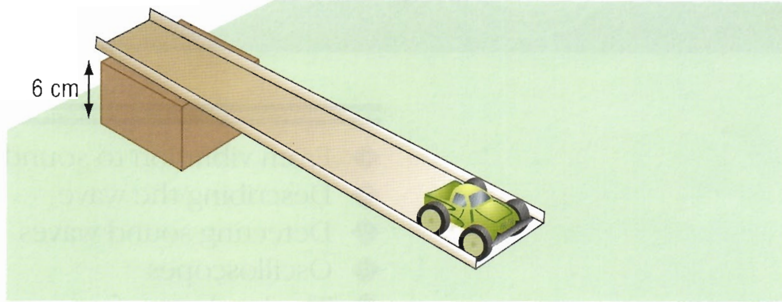


Figure 13.6

a) How many times was the height of the ramp changed?

b) How is an average calculated?

c) Calculate the average distance travelled for each height of the ramp.

d) Plot a graph to show the relationship between the height of the ramp and the distance travelled from the ramp by the car.

e) What conclusions can you draw from your analysis of the results of this investigation?

Table 13.2

Height/ cm	Distance/cm			
6	20	21	20	19
7	24	25	22	21
8	32	32	33	33
9	40	40	39.5	38
10	45	42	45	44
11	55	53	55	55
12	60	60	58	59
13	67	62	63	64

2 Figure 13.7 shows the distance/time graph for a travelling object.

a) How far did the object move in the first two seconds?

b) Why is the line horizontal between 3 and 6 seconds?

c) Draw a distance/time graph for an object that travels at 15 cm/s for 1 second and then stops for 2 seconds.

d) Draw a distance/time graph for an object that travels at 5 cm/s for 5 seconds and then stops for 1 second.

e) Copy and complete this relationship: 'The steeper the line, the __________ the speed.'

3 A car travels 30 km in 1 hour and then 40 km in the second hour. Draw a distance/time graph for the whole journey.

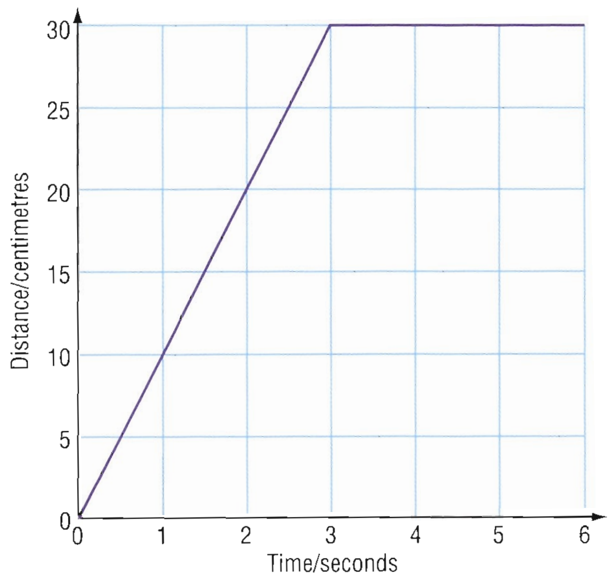


Figure 13.7

14 Sound

- From vibration to sound wave
- Describing the wave
- Detecting sound waves
- Oscilloscopes
- The loudness of a sound
- The pitch of a sound

Figure 14.1 Making a ruler vibrate

You have probably performed some experiments on sound without knowing it. At some time most people have made a ruler vibrate by holding one end over the edge of a desk and 'twanging' it. The end of the ruler moves up and down rapidly and a low whirring sound is heard which becomes higher as you pull in the ruler from the edge of the desk.

From vibration to sound wave

Any object can make a sound **wave** when it vibrates. In practical work on sound you might use an elastic band, a guitar string or a tuning fork because they all vibrate easily. A **vibration** is a movement about a fixed point. This movement may be described as a to-and-fro movement or a backwards and forwards movement (see Figure 14.2).

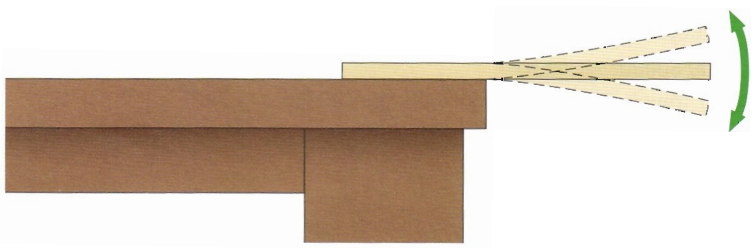


Figure 14.2 Vibration is a to-and-fro movement.

Sound waves can travel in a gas, a liquid or a solid because they all contain particles (see page 98). When an object vibrates it makes the particles next to it in the gas, liquid or solid vibrate too. For example, when an object vibrates in air it pushes on the air particles around it.

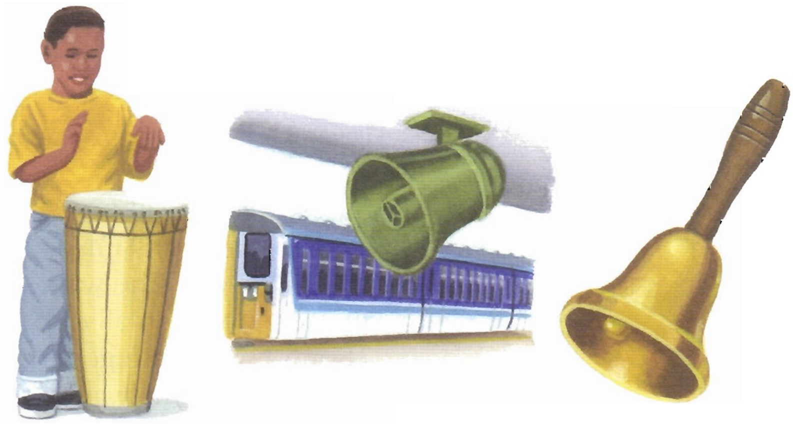


Figure 14.3 Producing sound by vibration

As the vibrating object moves towards the air particles, it squashes them together. The particles themselves are not compressed but the pressure in the air at that place rises because the particles are closer together (see Figure 14.4a).

As the object moves away from the air particles next to it, it gives them more space and they spread out and the pressure at that place falls (see Figure 14.4b).

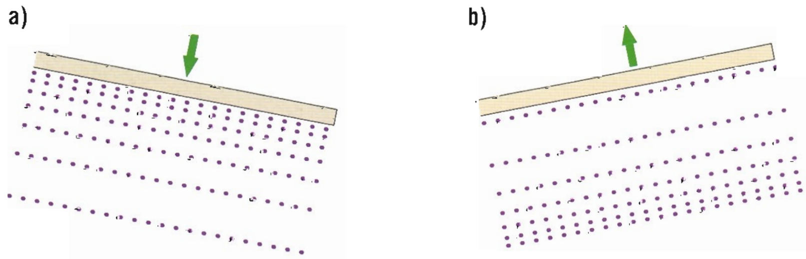


Figure 14.4 A vibrating object causes pressure variations in the air around it

As the object vibrates the air particles nearby also move backwards and forwards and they in turn cause other air particles further away to squash together and then spread out. This makes alternate regions of high and low pressure which travel through the air away from the vibrating object (see Figure 14.5).

1 When a table tennis ball on a thread is made to touch the vibrating prong of a tuning fork the ball swings backwards and forwards. How can this demonstration be used to explain how sound waves are made?

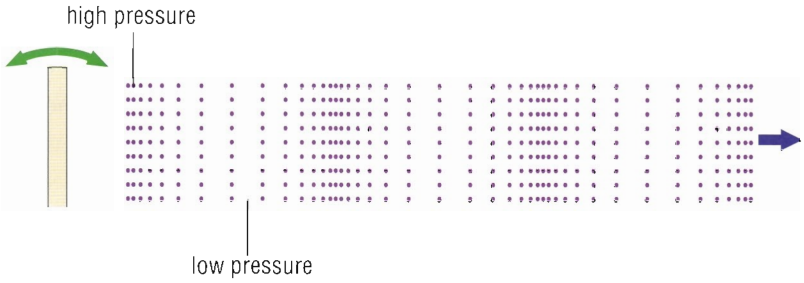


Figure 14.5 Regions of high and low pressure move away from the vibrating object.

If these changes in pressure are plotted on a graph they make a waveform similar to that shown in Figure 14.9 (see page 166). The waves of sound move out from the vibrating object in all directions.

Sound waves are generated and travel in liquids and solids in the same way as they do in gases. The particles in liquids and solids are held close together by forces of attraction (see page 96). In a liquid, however, the particles are further apart than in a solid and can move around one another. Sound travels very well through a liquid. It moves faster and further than it does in a gas.

The humpback whale emits a series of sounds, called songs, which travel thousands of kilometres through the ocean. It uses its songs to communicate with other whales.

Figure 14.6 These whales communicate by sound waves.

When sound travels through a solid it moves even faster than through a liquid because of the close interaction of the particles. However, the sound does not travel so far.

A snake detects vibrations in the ground with its lower jaw bone. The bone transmits the vibrations to the snake's ears and allows the snake to detect the footsteps of its prey.

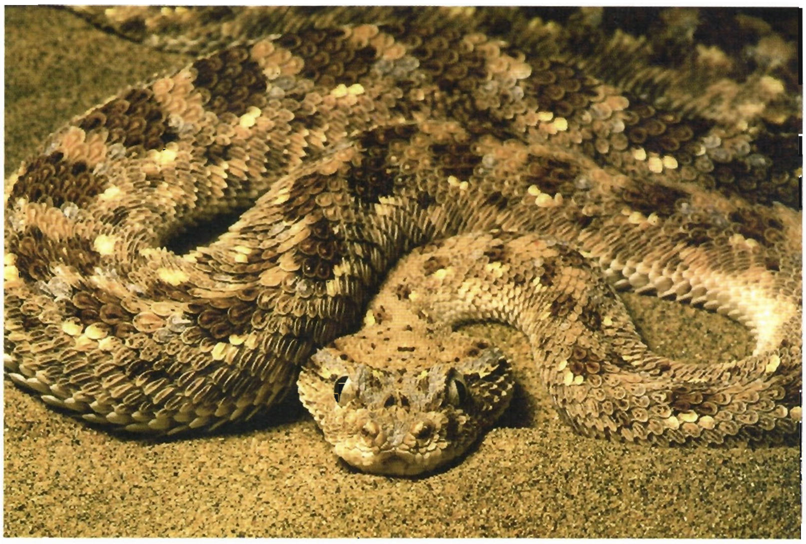


Figure 14.7 This snake is listening for vibrations in the ground.

Sound waves cannot pass through a vacuum because it does not contain any particles. Figure 14.8 shows an experiment that demonstrates this. As air is drawn out of the bell jar with a pump, the sound of the bell becomes quieter. When a vacuum is established in the bell jar, the bell cannot be heard although the hammer can be seen striking it.

2 Why is it that a bell in a sealed bell jar:

a) can be heard when the jar is full of air

b) cannot be heard when a vacuum is created in the jar?

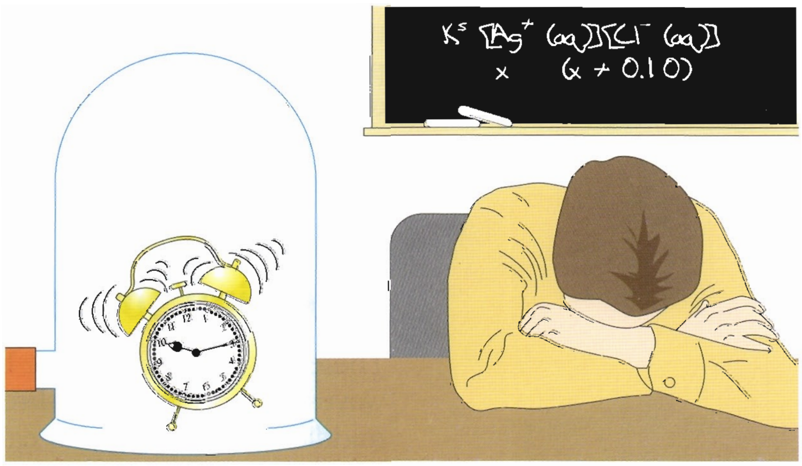


Figure 14.8 Sound cannot be heard through a vacuum.

Describing a wave

Figure 14.9 shows the different positions that particles can occupy when a sound wave is produced. This type of graph is called a displacement/distance graph.

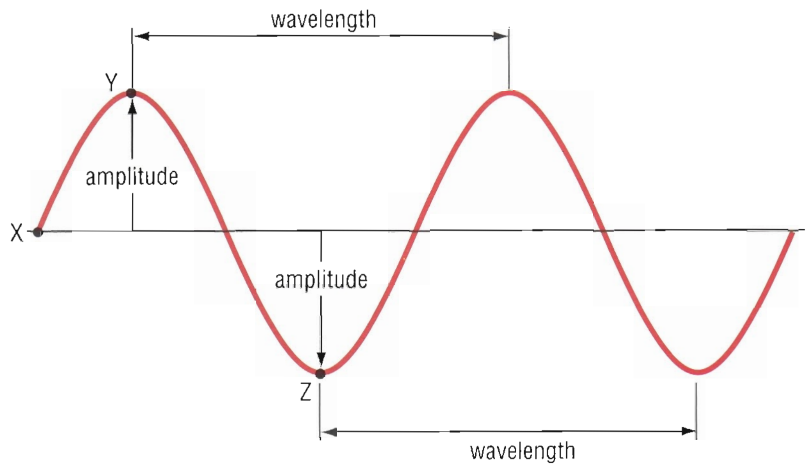


Figure 14.9 Displacement/distance waveform for a sound wave

A particle at position X (see Figure 14.9) is moving through the 'rest' position, a particle at Y has moved the maximum distance in one direction and one at Z has moved the maximum distance in the other direction.

3 Can you think of other ways of describing the wavelength of a wave?

Two characteristics of the wave that can be seen in Figure 14.9 are the **amplitude** and the **wavelength**. The amplitude is the height of the crest or the depth of the trough and shows the maximum **displacement** of the particles from their rest position. The wavelength is the distance from the top of one crest to the top of the next crest or from the bottom of one trough to the bottom of the next trough.

Detecting sound waves

The ear is the organ of the body that detects sound waves. It is divided into three parts: the outer ear, the middle ear and the inner ear (see Figure 14.10).

When sound waves reach the outer ear some pass directly down the middle of the tube called the auditory canal. Some waves which strike the outer part of the ear are reflected into the auditory canal. At the end of the auditory canal is a thin membrane which stretches across it. This is called the eardrum. When sound waves reach the eardrum they push and pull on it and make it vibrate.

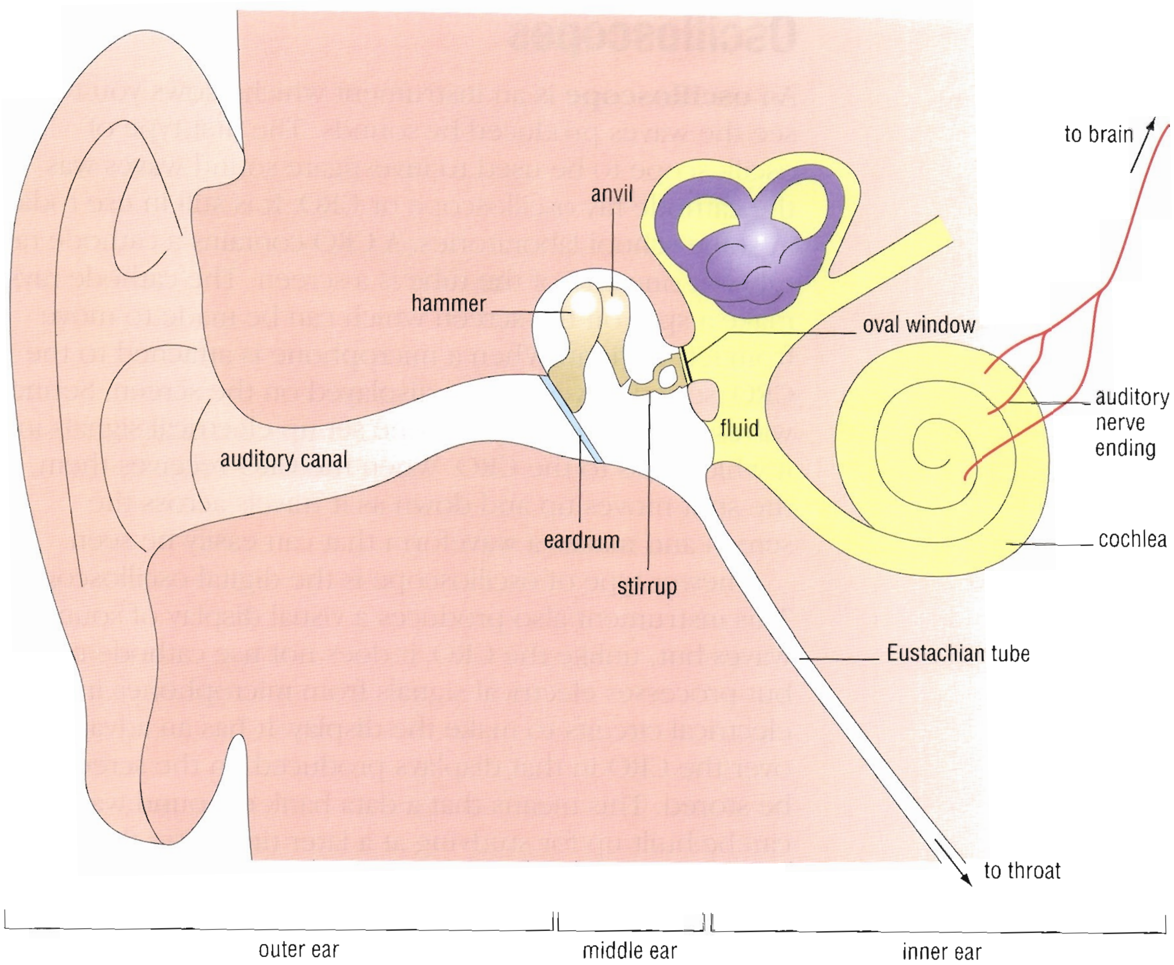


Figure 14.10 Structure of the ear

The vibrations of the eardrum pass through the three ear bones called the hammer, the anvil and the stirrup, after their shapes. The way the bones are connected together makes the vibrations increase in strength so that, when they reach the oval window, they set up vibrations in the ear fluid. These travel into the cochlea where there is a long row of tiny fibres. Each fibre only vibrates in response to a sound wave with a particular pitch (see pages 170–171). When a fibre vibrates it stimulates a nerve ending and a nerve impulse or message is sent to the brain where we become aware of the sound.

If very loud sounds enter the ears the vibrations set up in the ear fluid are so strong that they damage the fibres and stop the nerve endings being stimulated. This can produce permanent ear damage and deafness.

4 Why do people put a hand to their ear when they are listening to someone who is whispering?

5 What may happen to the ears of people who wear headphones and turn up the sound?

Oscilloscopes

An **oscilloscope** is an instrument which allows you to see the waves produced by sounds. The first type of oscilloscope to be used to investigate sound waves was the cathode ray oscilloscope or CRO. It is still in use today in some school laboratories. A CRO contains a cathode ray tube. At one end of the tube is a screen. The cathode rays make a spot on the screen which can be made to move from left to right. When a microphone is attached to the CRO, sound waves can be displayed on the screen. Sound waves striking the microphone set up electrical signals in it which pass to the CRO. When the CRO receives them, the spot moves up and down as it travels across the screen and makes a waveform that can easily be seen.

A newer type of oscilloscope is the digital oscilloscope. This instrument also produces a visual display of sound waves but, unlike the CRO, it does not use cathode rays but processes electrical signals from microphones in electrical circuits to make the display. It has an advantage over the CRO in that displays produced on the screen can be stored. This means that a data bank of sound waves can be built up for studying at a later time after the practical part of an investigation.

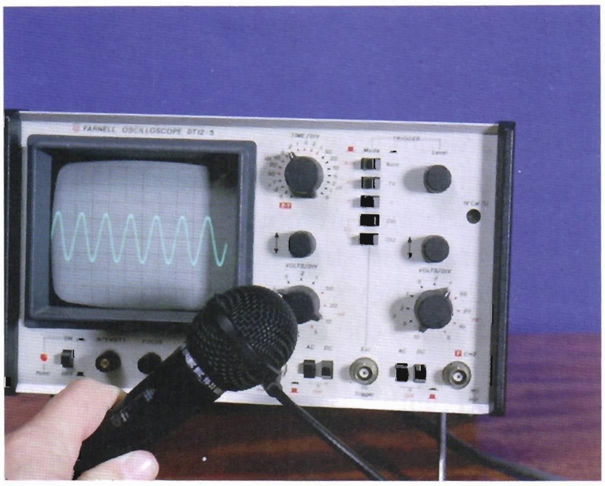


Figure 14.11 A cathode ray oscilloscope displaying a sound wave

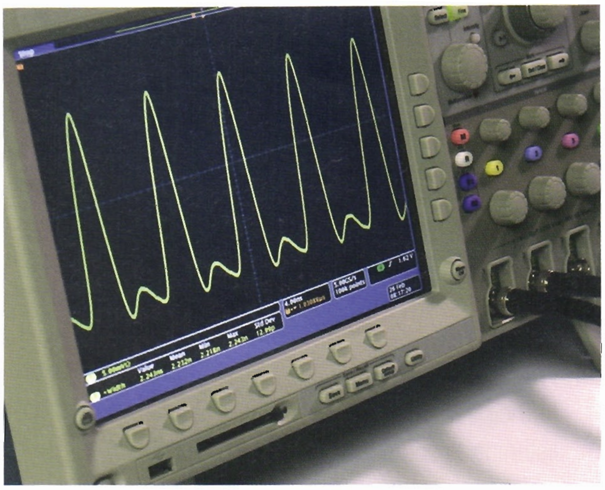


Figure 14.12 A digital oscilloscope displaying a sound wave

The loudness of a sound

The **loudness** of a sound is related to the movement of the vibrating object. If an object only moves a short distance from its rest position, it will produce a sound wave with only a small amplitude and the sound that is

Loudness and energy

Sound energy passes through the air as the particles move to and fro. When a wave with a small amplitude is generated, a small amount of energy passes through the air. When a wave with a large amplitude is generated, a large amount of energy passes through it. The energy of a sound wave is converted into other forms such as movement energy in the eardrum and ear bones.

Loudness and deafness

The vibrating air particles of a very loud sound can produce such a strong pushing and pulling force on the eardrum that a hole is torn in it. The eardrum is said to be perforated. It no longer vibrates efficiently and the person loses his or her hearing. The eardrum can heal and normal hearing can be restored.

If a person is exposed to a very loud sound or a particular note for a long period of time, he or she will no longer be able to hear it. This is due to permanent damage to a nerve ending in the cochlea. People who perform in pop groups are at risk of developing this kind of deafness, called nerve deafness. In time they may be unable to hear a range of notes which they frequently used in their music. People who work in noisy surroundings, such as airport workers or metal workers in a factory, wear ear protection in the form of ear muffs which cover the ears and reduce the amount of sound energy entering the ears.

A common form of partial deafness, which is not related to the loudness of a sound, is the development of ear wax in the outer ear. This stops sound waves reaching the eardrum. The wax can be removed under the medical supervision of a nurse.

Some people have growths of tissue in their middle ears which stop the ear bones moving freely. They may be prescribed a hearing aid. This contains a microphone and amplifier and compensates for some of the loss of amplification that was provided by the ear bones.

6 What kind of ear damage might be caused by a loud explosion? Explain your answer.

For discussion

To prevent ear damage, how should you use earphones on a music player? Where should you dance at a disco and where should you sit or stand at a pop concert?

How far do you follow the advice you have given in your answer to the above?

The pitch of a sound

You probably have an idea about the **pitch** of a sound even if you do not know the word. You might describe a sound as a high sound or a low sound, which really means a high-pitched or a low-pitched sound. For example, when

heard will be a quiet one. If an object moves a large distance from its rest position, it will produce sound waves with a large amplitude and the sound that is heard will be a loud one.

a)

b)

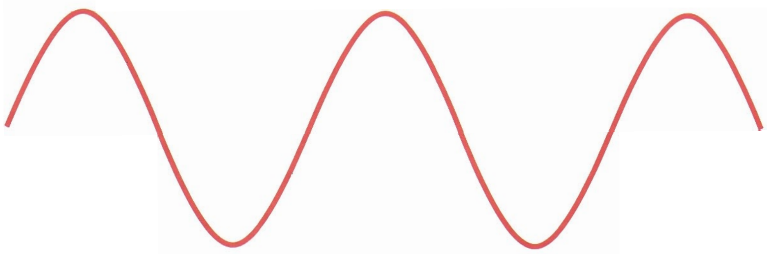


Figure 14.13 Displacement/distance waveform of **a)** a quiet sound and **b)** a loud sound

Figure 14.14 Wearing ear prevents ear damage.

The loudness of a sound is measured in decibels (see Table 14.1).

Table 14.1 The loudness values of different sounds

Sound	Loudness/decibels
the sound hurts	140
a jet aircraft taking off	130
a road drill	110
a jet plane overhead	100
a noisy factory floor	90
a vacuum cleaner	80
a busy street	70
a busy department store	60
normal speech	55
voices in a town at night	40
a whisper	20
rustling leaves	10
limit of normal hearing	0

you say 'bing' you are making a higher-pitched sound than when you say 'bong'.

The pitch of the sound an object makes depends on the number of sound waves it produces in a second as it vibrates. This number of waves per second is called the **frequency**. The frequency of a sound is measured in hertz (*abbreviation*: Hz). The higher the frequency of the wave, the higher the pitch of the sound.

Figure 14.15 shows the positions that particles occupy at different times as the wave passes. These graphs are called displacement/time graphs. The higher-frequency waves have a shorter wavelength than the lower-frequency waves. Sound waves share this property with light waves (see page 176).

7 The following are three frequencies of sound waves: 1800 Hz, 50 Hz, 10 000 Hz.

a) Which has the highest pitch and which has the lowest pitch?

b) What does Hz stand for?

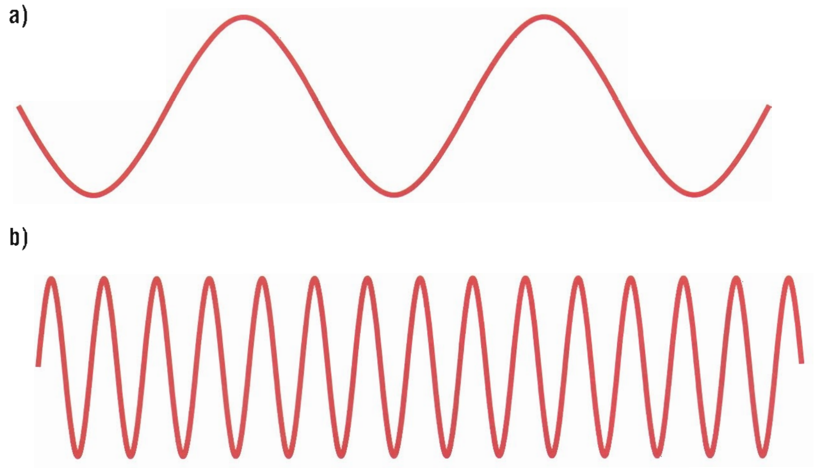


Figure 14.15 Displacement/time waveform of **a)** a low-frequency sound **b)** a high-frequency sound

The ear of a young person is sensitive to frequencies in the range 20 to 20 000 hertz but the ability to detect the higher frequencies decreases with age. Some people may have a restricted range of hearing due to nerve damage. They may not be able to hear some low-pitched or high-pitched sounds.

Early experiments on the speed of sound

In the past many scientists have performed experiments to find the speed of sound. Isaac Newton (1642–1727) investigated the speed of sound by measuring the time between a sound being made and its echo from a wall being heard. Other scientists measured the time taken between seeing a distant cannon fire and hearing its sound.

The speed of sound in water was investigated using the apparatus shown in Figure B. The experiment was performed at night. When the lever was pulled down both the arm carrying the bell hammer and the device carrying the match moved.

Figure A Measuring the speed of sound in air

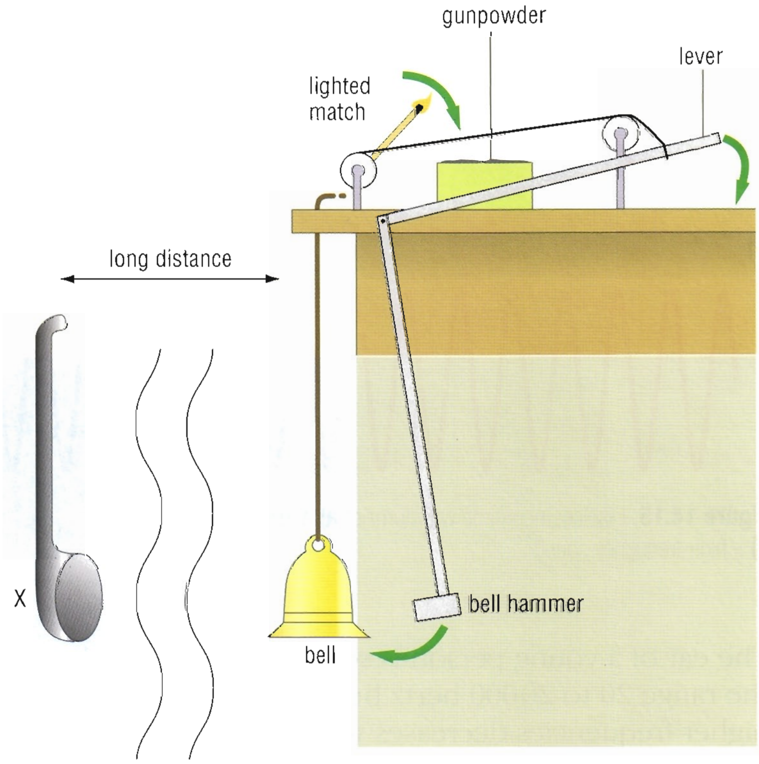


Figure B Measuring the speed of sound in water

1 What is an echo?

2 What measurement, besides time, needs to be taken in all the experiments to determine the speed of sound?

3 In Figure B, what is the purpose of:

a) the gunpowder

b) the apparatus marked X?

4 Why do you think the experiment to find the speed of sound in water was done at night?

5 Construct a plan to measure the speed of sound in water using the equipment shown in Figure B.

SUMMARY

- Sounds are made by vibrating objects (*see page 162*).
- Sound travels through materials as waves of vibrating particles (*see page 163*).
- There are three parts to the ear. Each part plays an important role in hearing (*see pages 166–167*).
- An oscilloscope can be used to investigate sound waves (*see page 168*).
- The loudness of a sound is related to the amplitude of its waves (*see pages 168–170*).
- The pitch of a sound is related to the frequency of its waves (*see pages 170–171*).

End of chapter question

Describe how the vibration of a ruler is detected in the inner part of your ear.

15 Light

- Light rays
- Classifying non-luminous objects
- Shadows
- Reflecting light
- Passing light through transparent materials
- The prism
- The rainbow
- Colour

Light is a form of **energy**. It is a form of **electromagnetic radiation**. Objects that emit light are said to be **luminous** while those that do not emit light are said to be **non-luminous**. Non-luminous objects can only be seen if they are reflecting light from a luminous source. The Moon is a non-luminous body – the 'moonlight' it produces is reflected sunlight. Most luminous objects, such as the Sun, stars, fire and candle flames, release light together with a large amount of heat.

1 What is the luminous object which is providing light for you to read this book?

Figure 15.1 A bonfire is luminous: it radiates light and heat.

Light rays

Light leaves the surface of a luminous object in all directions but if some of the light is made to pass through a hole it can be seen to travel in straight lines.

For example, when sunlight shines through a small gap in the clouds it forms broad sunbeams with straight edges (see Figure 15.2). The path of the light can be seen because some of it is reflected from dust in the atmosphere. Similarly, sunlight shining through a gap in the curtains of a dark room produces a beam of light which can be seen when the light reflects from the dust in the air of the room.

Figure 15.2 Although the Sun radiates light in all directions, the sides of sunbeams seem almost parallel because the Sun is a very distant luminous object.

Smaller lines of light, called **rays**, can be made by shining a lamp through slits in a piece of card.

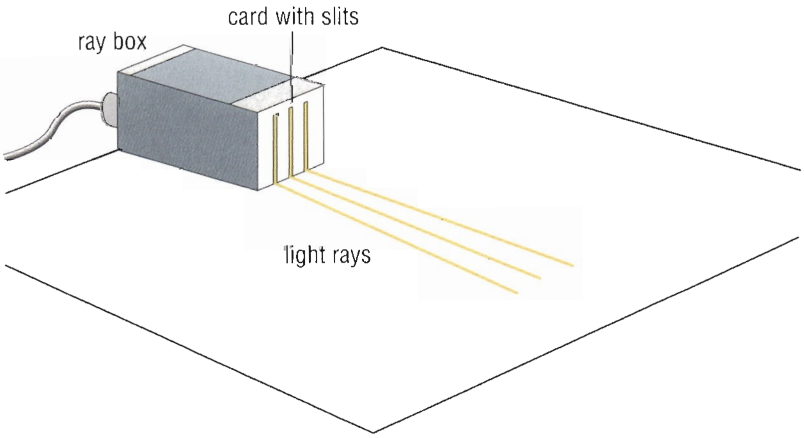


Figure 15.3 Making rays of light

What is light?

Empedocles (about 490–430 BCE) was a Greek philosopher who believed that we see things because our eyes send out rays which touch objects. Plato (427–347 BCE) built on this idea but believed that objects gave out rays which the eyes' rays intercepted. Democritus (about 470–380 BCE) believed that objects were made of atoms, some of which passed from the objects through the air to the eye and allowed us to see the objects.

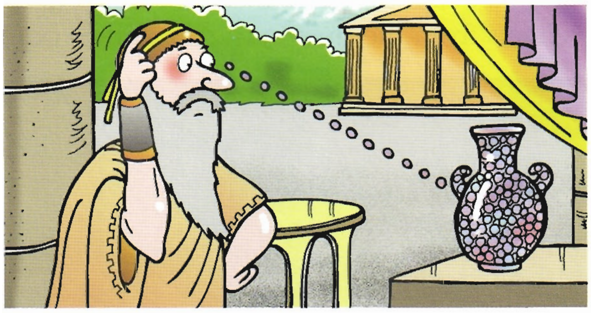


Figure A Democritus thought that sight involved moving atoms.

1. How do you think Empedocles came up with his idea through creative thinking?
2. Which part of Empedocles' idea did Plato use to develop his explanation?
3. What idea did Democritus produce through his creative thinking that built on the ideas of the other philosophers?
4. Which piece of scientific knowledge did Young use to explain his results?
5. Which piece of scientific knowledge do you think von Lenard used to come to his conclusion?

Figure B Did light travel like waves in a puddle?

Christian Huygens (1629–1695), a Dutch physicist, put forward a wave theory of light in which he claimed that light moved in a similar way to waves of water. He thought the waves were very small and for most experiments they did not affect the light rays which could be considered as travelling in straight lines.

In 1801 Thomas Young (1773–1829), an English physicist, performed an experiment in which he shone a light through narrow, close slits as shown in Figure C. The result could not be explained if light travelled as particles such as atoms but could be explained by the wave theory. Young believed that the regions where the light was brightest were where the crests of the light waves met together and the regions of darkness were where the troughs of the waves cancelled out the crests (see Figure D).

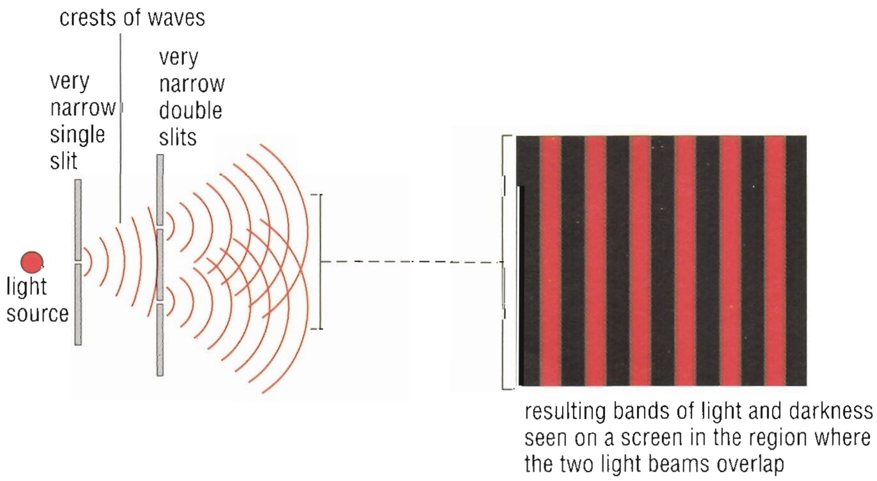


Figure C Young's experiment

Philip von Lenard (1862–1947), a Hungarian physicist, discovered that when light is shone onto certain metals, tiny electrically-charged particles called electrons are released from the metal surface. He found that a bright light released a greater number of electrons than a dim light. This suggested to him that light was made from 'particles of energy' which moved the electrons.

Further investigations into the nature of light reveal that it can be considered either to be waves or particles. The form that you consider it to be depends on the work that you are doing with light. For example, if the way light passes through transparent objects is being studied, the light can be considered to be formed of waves. But if the way in which light makes the solar cells on a calculator generate electricity is being studied, the light can be considered to be made of 'particles' of energy which scientists now call photons.

You may have trouble thinking that light can be considered in two different ways. It may help this problem if you think about how we consider people in different ways. The way you behave when with an older person, such as a parent, is different to the way you behave with people of your own age. Both older and younger people see you in different ways. Possibly none of them see the 'real' you!

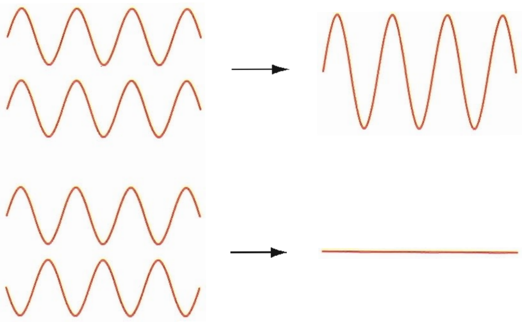


Figure D How the crests and troughs combine

Figure E These cars are powered by photons which strike the solar cells on their surface.

Classifying non-luminous objects

Non-luminous materials can be classified as **transparent**, **translucent** or **opaque** according to the way light behaves when it meets them. When light shines on a transparent material, such as glass in a window, it passes through it and so objects on the other side of it can be seen clearly.

When light shines on a translucent object, such as tracing paper, some of the light passes through but many light rays are scattered. Objects on the other side cannot be seen clearly unless they are very close to the translucent object.

When light shines on an opaque object none of the light passes through it.

Shadows

When a beam of light shines on an opaque object the light rays which reach the object are stopped while those rays which pass by the edges continue on their path. A region without light, called a **shadow**, forms behind the object. The shape of the shadow may not be identical to the shape of the object because the shadow's shape depends on the position of the light source and on where the shadow falls.

The size and intensity of the shadow depends on the size of the light source and the distance between the light source and the object. A small light source gives a sharp shadow that is equally dark all over. A larger light source gives a shadow with a dark central region and a lighter shadow surrounding it.

Shadows can be formed by the Moon and the Earth.

For discussion

How might the shadow of a brick appear if light travelled in a curve from the light source?

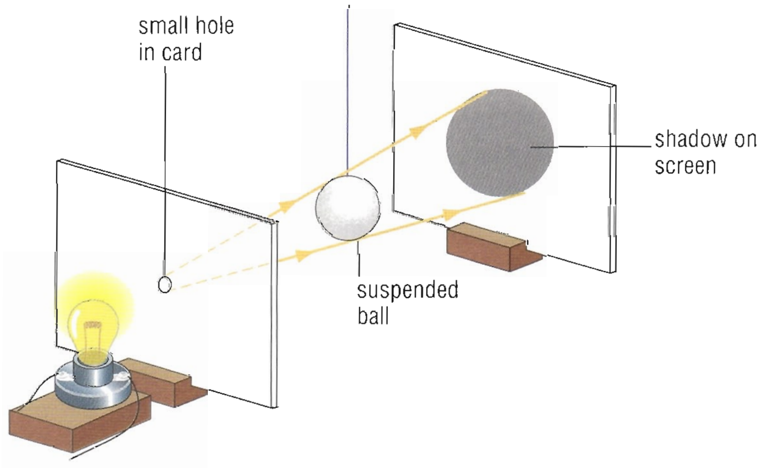


Figure 15.4 The formation of a shadow by a small light source

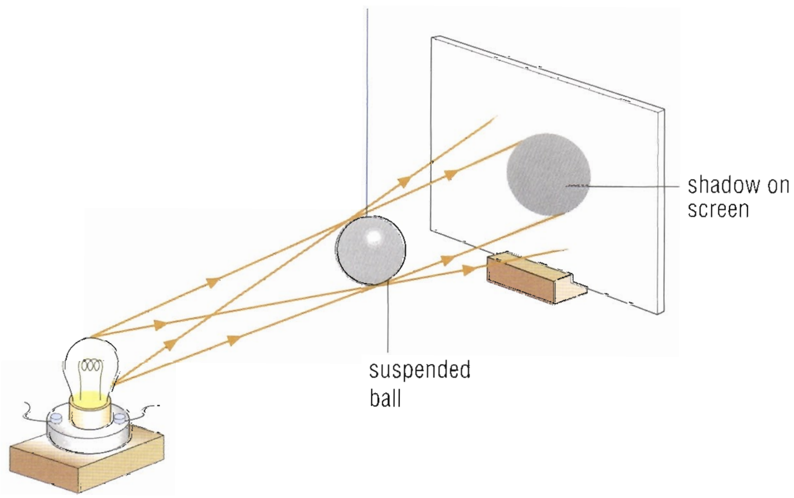


Figure 15.5 The formation of a shadow by a large light source

If the light source is close to the object it makes a bigger shadow than if it is further away.

Reflecting light

Your bedroom is probably full of objects but if you wake in the middle of the night you cannot see them clearly because they are not luminous. You can only see them by reflected light and, unless your room is partially lit by street lights or other lights, the objects will not be clearly seen until sunrise. The way light is reflected from a surface depends on whether the surface is smooth or rough.

Studying reflections

A few terms are used in the study of light which make it easier for scientists to describe their investigations and ideas. In the study of **reflections** the following terms are used:

- **Incident ray**: a light ray that strikes a surface
- **Reflected ray**: a light ray that is reflected from a surface
- **Normal**: a line perpendicular (that is at 90°) to the surface where the incident ray strikes
- **Angle of incidence**: the angle between the incident ray and the normal
- **Angle of reflection**: the angle between the reflected ray and the normal
- **Plane mirror**: a mirror with a flat surface
- **Image**: the appearance of an object in a smooth, shiny surface. It is produced by light from the object being reflected by the surface.

The ways in which the incident ray, normal and reflected ray are represented diagrammatically are shown in Figure 15.6. The back surface of a mirror is usually shown as here, as a line with short lines at an angle to it.

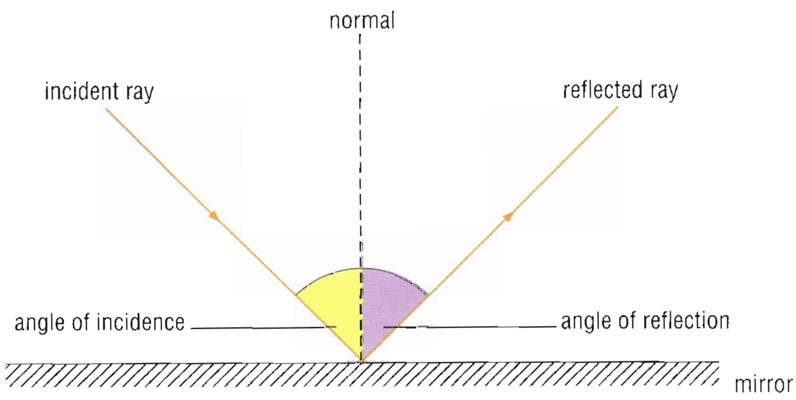


Figure 15.6 The reflection of light from a plane mirror

2 Figure 15.8 shows three drawings made of the paths of incident and reflected rays in an experiment using the apparatus in Figure 15.7. Use a protractor to measure the angles of incidence and angles of reflection. What do these drawings tell you about the process of reflection?

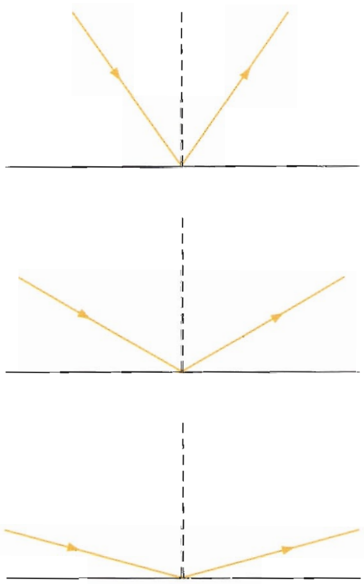


Figure 15.8

The way light rays are reflected from a plane mirror can be investigated using the apparatus shown in Figure 15.7.

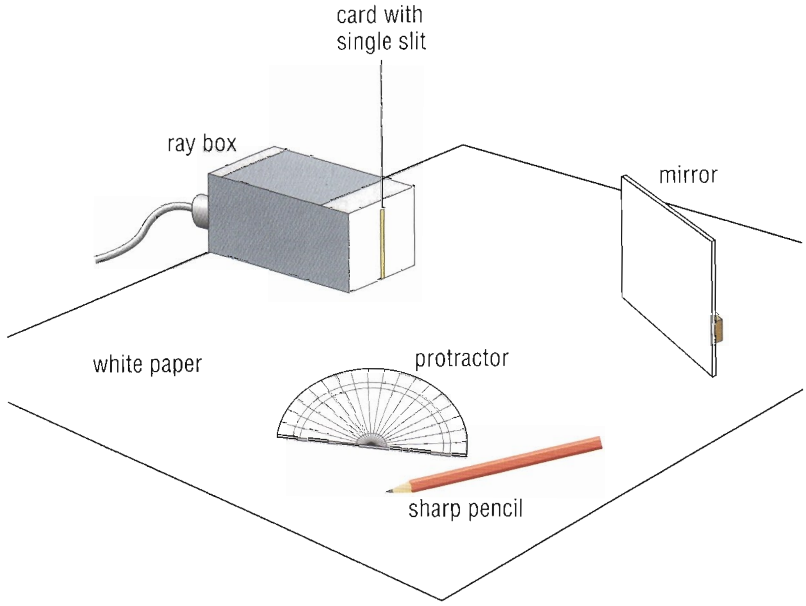


Figure 15.7 Apparatus to investigate reflection from a plane mirror

Objects with smooth surfaces

Glass, still water and polished metal have very smooth surfaces. Light rays striking their flat surfaces are reflected as shown in Figure 15.9. The angle of reflection is equal to the angle of incidence. When the reflected light reaches your eyes you see an image (see Figure 15.10).

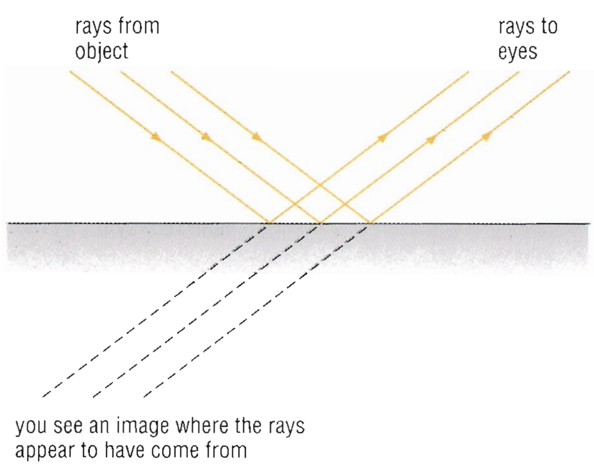


Figure 15.9 Regular reflection from a smooth surface

Figure 15.10 Light reflected from the smooth surface of a lake can produce an image in the water.

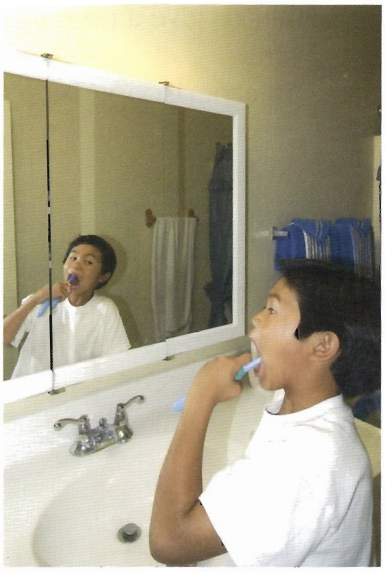


Figure 15.11 Your image in a mirror is the wrong way round.

Two types of images

There are two types of images that can be formed with light. They are real images, such as those produced on a cinema screen by biconvex lenses, and virtual images, which cannot be projected onto a surface but only appear to exist, such as those in a plane mirror or other smooth, shiny surface.

The virtual image of yourself that you see when you look in a plane mirror is the same way up as you are, is the same size as you are, and is at the same distance from the mirror's surface as you are but behind the mirror instead of in front of it.

The main difference between you and your virtual image is that the virtual image is the 'wrong way round' – for example, your left shoulder appears to be the right shoulder of your virtual image.

Figure 15.12 Some of the people in this scene are using periscopes to help them see over the crowd.

3 Copy Figure 15.13 and draw in the path of a ray of light travelling from the golfer to the eye.
4 Why is a periscope useful on a submarine?

The periscope

Two plane mirrors may be used together to give a person at the back of a crowd a view of an event.

The arrangement of the mirrors in a periscope is shown in Figure 15.13.

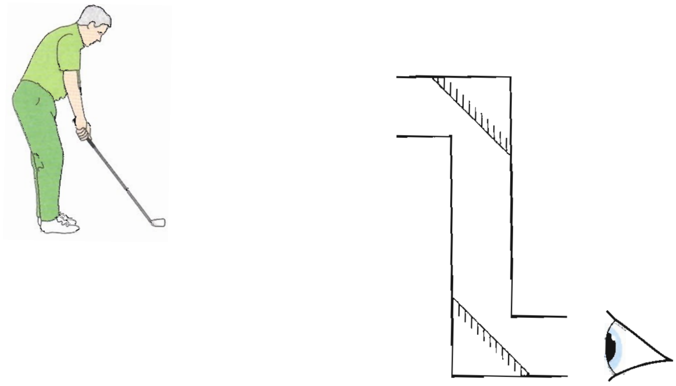


Figure 15.13 A simple periscope

Objects with rough surfaces

Most objects have rough surfaces. They may be very rough like the surface of a woollen pullover or they may be only slightly rough like the surface of paper. When light rays strike any of these surfaces the rays are scattered in different directions (see Figure 15.14).

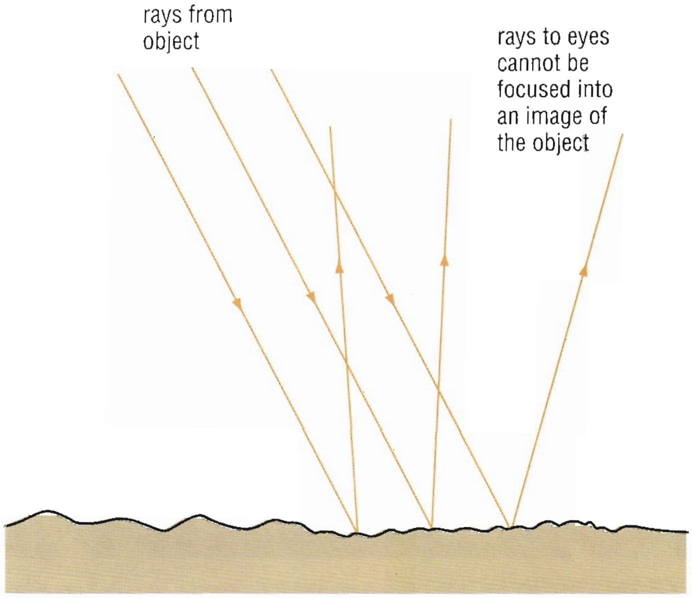
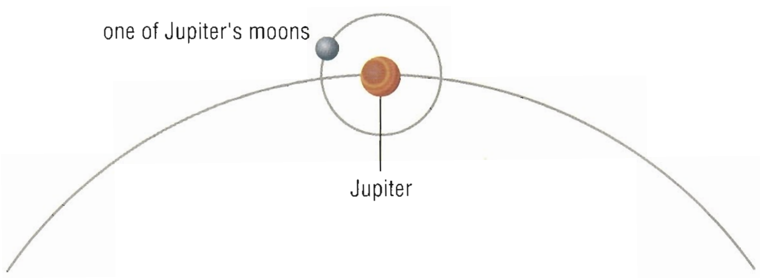


Figure 15.14 Light rays are scattered by a rough surface

You see a pullover or this page by the light scattered from its surface. You do not see your face in a piece of paper because the reflection of light is irregular so does not form an image.

The speed of light

The Ancient Greeks believed that light travelled at infinite speed and this remained unchallenged until Ole Rømer (1644–1710), a Danish astronomer, observed the moons of Jupiter and studied how they travelled around the planet. When Jupiter was between the Earth and one of its moons, the moon could not be seen from the Earth and was said to be eclipsed by Jupiter. The four large moons move around Jupiter quite quickly and other scientists had found it possible to time them. When Rømer studied the eclipses more thoroughly, he discovered that they appeared to occur earlier when the Earth was nearer Jupiter in its orbit than when it was further away (see Figure A).



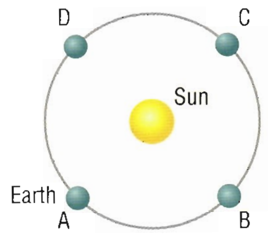


Figure F The positions of the Earth in its orbit when Rømer made his observations

Rømer did not believe that the moons speeded up at different times of year. He believed the difference was due to light having a finite speed and that it took longer to reach the Earth when the Earth was at points A and B than when it was at points C and D. By taking measurements and making calculations, Rømer deduced a speed of light which showed that light took 11 minutes to get from the Sun to Earth.

James Bradley (1693–1762), an English astronomer, studied the position of the stars at different times of year as the Earth moved in its orbit. From his studies he calculated the speed of light. His results showed that light took 8 minutes 11 seconds to travel from the Sun to the Earth.

In 1849 Armand Fizeau (1819–1876), a French physicist, made an instrument which measured the speed of light from a candle placed 9 kilometres away. He made many measurements and calculated that light travels at a speed of 314 262 944 metres per second.

Many other scientists refined Fizeau's work by making more complicated pieces of apparatus and today the speed of light has been measured as 299 992 460 metres per second in a vacuum, slightly slower in air and even slower in water and glass. The speed of light in air is often rounded to 300 000 000 metres per second and the average time taken for light to travel from the Sun to the Earth has been measured as 8 minutes and 17 seconds.

Figure G Armand Fizeau

6 What evidence about the speed of light had Rømer to work with when making his studies?
7 What two pieces of evidence about Jupiter's moons did Rømer use to plan his investigation?
8 What did Rømer's measurements show?
9 What creative thought did Rømer have to explain his measurements?
10 How accurate was Bradley's calculation of the time it takes light to reach the Earth from the Sun? Explain your answer.
11 How accurate was Fizeau's value for the speed of light compared to the current-day value? Explain your answer.

Passing light through transparent materials

If a ray of light is shone on the side of a glass block as shown in Figure 15.15a the ray passes straight through but, if the block is tilted, the ray of light follows the path shown in Figure 15.15b.

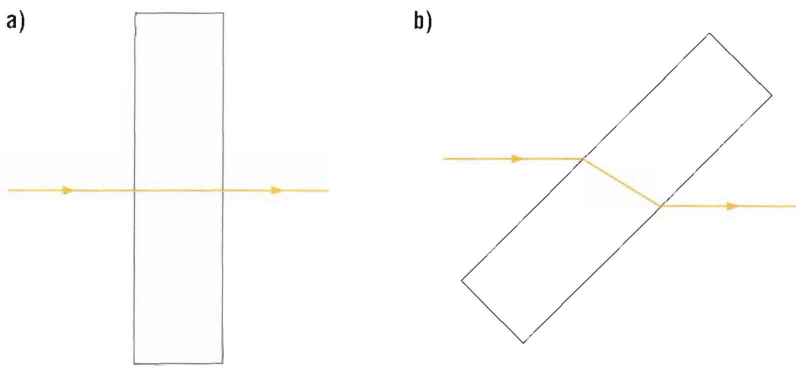


Figure 15.15 Light is refracted if the incident ray is not at 90° to the surface of the transparent material.

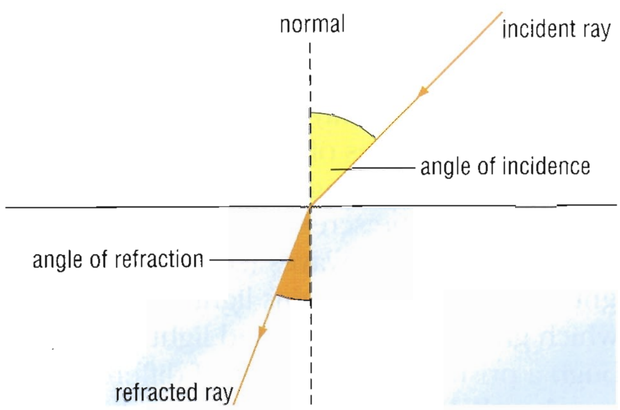


Figure 15.16 The angle of incidence and the angle of refraction

This 'bending' of the light ray is called **refraction**. The angle that the refracted ray makes with the normal is called the angle of refraction (see Figure 15.16).

The refraction of light as it passes from one transparent substance or 'medium' to another is due to the change in the speed of the light. Light travels at different speeds in different media. For example, it travels at almost 300 million metres per second in air but only 200 million metres per second in glass. If the light slows down when it moves from one medium to the other, the ray bends towards the normal. If the light speeds up as it passes from one medium to the next, the ray bends away from the normal.

5 How is the reflection of a light ray from a plane mirror (see page 179) different from the refraction of a light ray as it enters a piece of glass?

Light speeds up as it leaves a water surface and enters the air. A light ray appears to have come from a different direction than that of the path it actually travelled (see Figure 15.17). The refraction of the light rays makes the bottom of a swimming pool seem closer to the water surface than it really is. It also makes streams and rivers seem shallower than they really are and this fact must be considered by anyone thinking of wading across a seemingly shallow stretch of water. The refracted light from a straw in a glass of water makes the straw appear to be bent.

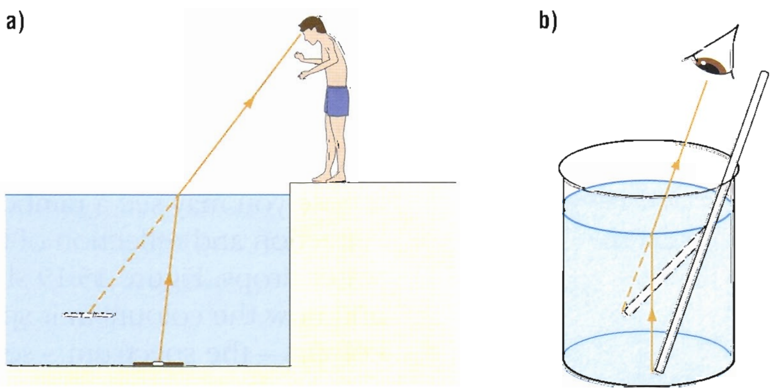


Figure 15.17 Refraction of light as it passes from water to air makes an object appear closer to the surface than it really is.

The prism

A triangular prism is a glass or plastic block with a triangular cross section. When a ray of sunlight is shone through a prism at certain angles of incidence and its path is stopped by a white screen, a range of colours, called a **spectrum**, can be seen on the screen.

Light behaves as if it travels as waves (see page 176). The 'white' light from the Sun contains light of different wavelengths which give different coloured light. When they pass through a prism the light waves of different wavelengths travel at slightly different speeds and are spread out, by a process called **dispersion**, to form the colours of the spectrum. The light waves with the shortest wavelengths are slowed down and refracted the most.

6 Look at Figure 15.18. Which colour of light has the shortest wavelength? Explain your answer.

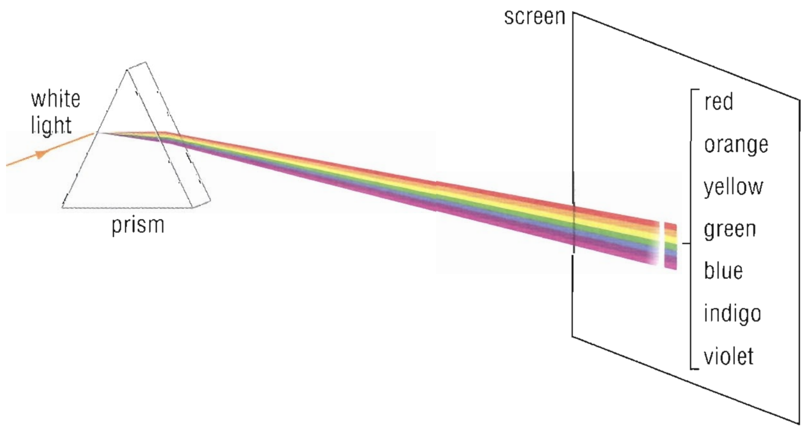


Figure 15.18 White light passing through a prism is split up into its constituent colours, forming a spectrum.

The rainbow

If you stand with your back to the Sun when it is raining or you look into a spray of water from a fountain or a hose you may see a rainbow. It is produced by the refraction and reflection of the Sun's light through the water drops. Figure 15.19 shows the path of a light ray and how the colours in it spread out to form the order of colours – the spectrum – seen in a rainbow.

Sometimes a second, weaker rainbow is seen above the first because two reflections occur in each droplet. In the second rainbow the order of colours is reversed.

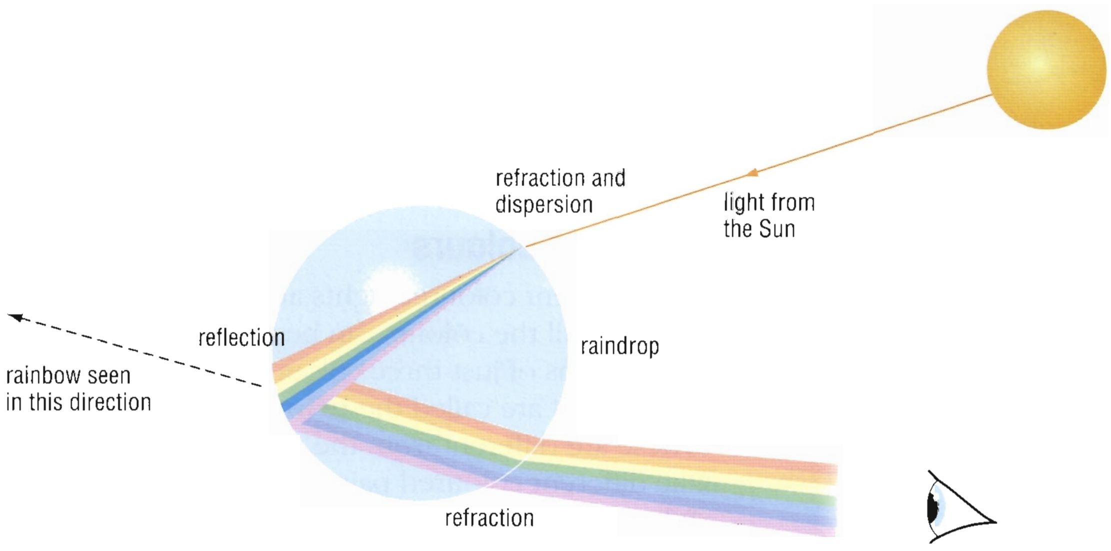


Figure 15.19 The formation of a rainbow

Colour

Absorbing and reflecting colours

When a ray of sunlight strikes the surface of an object, all the different colours in it may be reflected or they may all be absorbed. If all the colours are reflected the object appears white; if all the colours are absorbed the object appears black.

Most objects, however, absorb some colours and reflect others. For example, healthy grass reflects mainly green and absorbs other colours.

7 Name some everyday objects which:
a) reflect all the colours in sunlight
b) absorb all the colours in sunlight.

Filtering colours

Sheets of coloured plastic or glass can filter the colours in light. They absorb some of the colours and allow other colours to pass through, producing different coloured light. For example, a blue filter allows only blue light to pass through and a red filter allows only red light to pass through.

One of the most spectacular uses of colour filters is in the theatre where the stage is bathed in different coloured lights to give different effects. Blue light is used for night scenes or to generate scary feelings or excitement while red and yellow can make dance routines seem even more lively.

Colour filters are also used in photography to produce images for art exhibitions and advertising campaigns.

Figure 15.20 Green coloured filters in use at a rock concert

8 The colours on a television or computer screen are made by three different colours of substances called phosphors.
They glow to release their colour of light. What do you think the colours of the phosphors are?
Explain your answer.

9 Which primary colours overlap to produce:
a) yellow
b) magenta
c) cyan
d) white light?

For discussion

Identify the light source you are using for seeing things around you. Choose an object in the room. Describe the changes that take place in the light from when it leaves the source until it reaches your eyes from the object. Is it refracted through glass? Is it partially reflected from any surface? Which colours have been absorbed by the object?

In science colour filters are used for making parts of a view under investigation easier to see. For example a red filter used in a microscope absorbs the green light coming from chloroplasts and makes them appear dark. Telescopes can be fitted with filters which absorb the light produced by street lamps making objects in space more visible.

Combining colours

When different coloured lights are combined it is found that all the colours can be made from different combinations of just three colours. They are red, green and blue and are called the **primary colours** of light.

These are different from the primary colours needed to make different coloured paint (see below).

When beams of the three primary colours are shone onto a white screen so that they overlap they produce three secondary colours of light and white light (see Figure 15.22).

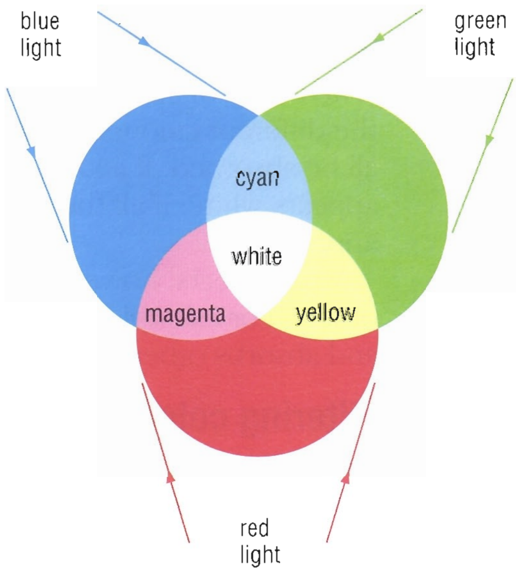


Figure 15.21 Overlapping beams of the primary colours form the secondary colours.

Colours and paint

Paint contains tiny particles called the pigment. The pigment absorbs some of the colours in sunlight and reflects others to give the paint its colour. Three colours of paint can be used to make almost all the other colours of paint. These colours are yellow, magenta and cyan. They are mixed together in different proportions to produce a wide range of colours. For example, when

Figure 15.22 The colours in this painting are due to the mixing of the pigments in the paints which absorb and reflect different amounts of colour in the white light shining on them.

yellow and magenta are mixed together reds are produced, when magenta and cyan are mixed blues are produced and when cyan and yellow are mixed greens are produced. Mixing all three produces black.

Three different colours of paint, ink or dye can be used to make almost all the other colours. These three colours are yellow, magenta and cyan. They are mixed together in different proportions to produce a wide range of colours, like those in the photographs in this book. Tiny dots of the three colours form the printed picture.

Detecting light

On page 176 we found that Empedocles thought we sent out rays to see and that Democritus thought that our eyes were bombarded by atoms from the objects we looked at. Today we know these ideas are wrong and some of the contents of this chapter can be brought together to show how our eyes let us see. Figure 15.23 shows the parts of the eye that are involved with light rays that shine towards us.

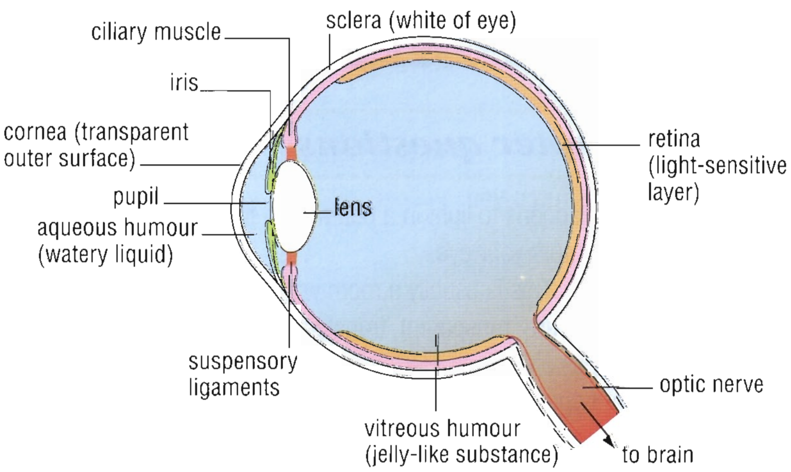


Figure 15.23 The structure of the right eye

Light rays strike the cornea and are refracted so that many of them change path as they move through the transparent aqueous humour and pass through the gap called the pupil. Once through this 'black hole' of the eye they are refracted again by the lens and travel on through the transparent vitreous humour to the retina where they form a picture on the light-sensitive cells. If the light is dim, as at dawn or dusk and at night, it causes rod-shaped cells in the layer to fire off messages along the optic nerve and we see a picture in black and grey. If there is more light, such as in the daytime, cone-shaped cells sensitive to red, green or violet light fire off messages to the brain and the brain merges the messages to produce the coloured picture we see.

10 Name three processes described in this chapter that are used when we see an object.

SUMMARY

- Light is a form of energy that is released from luminous objects (*see page 174*).
- Materials can be classified as opaque, translucent or transparent (*see page 177*).
- A shadow forms when light rays are stopped by an opaque object (*see page 178*).
- We see non-luminous objects by the light they reflect (*see page 179*).
- Light rays are reflected from a smooth surface at the same angle as that at which they strike it (*see page 179*).
- A real image can be formed on a screen but a virtual image cannot (*see page 181*).
- When light rays strike the surface of a transparent material at an angle to the perpendicular they are refracted (*see page 184*).
- A prism can split sunlight into different colours of light (*see page 186*).
- The colour of an object that we see depends on the colours of light that it absorbs and reflects (*see page 187*).

End of chapter questions

1 Describe what happens to light in a beam from the time it reaches the Earth from the Sun and shines upon a leaf to when it enters your eye.

2 Imagine a kitchen. This is usually a room with many types of surface. There are also objects with many colours and some are transparent, translucent or opaque. Describe what happens to the sunlight as it strikes the different types of surface. Here are two examples to help you begin your answer. Think of four more and describe what happens to light when it strikes them too.

- The white surface of a fridge
- The black surface of an oven hob

16 Magnetism

- The behaviour of magnets
- Inside a magnet
- The magnetic field
- The link between magnetism and electricity
- The electromagnet

Three metallic elements show strong magnetic properties. They are iron, cobalt and nickel. Steel is a metal alloy which can show magnetic properties. It is made from iron and carbon. Steel can also be mixed with other metals to make an alloy which does not show magnetic properties. For example, stainless steel is made from steel, chromium and nickel and it does not show magnetic properties.

Materials that show magnetic properties do not show them all the time. For example, steel paper clips do not generally attract and repel each other. When a material is showing magnetic properties it is said to be magnetised and is known as a **magnet**. The most widely used magnets used to be made from steel but most magnets are now made from mixtures of the magnetic metals. Alnico is an example.

1 Which three metals do you think might be present in Alnico? Explain your answer. Which ones are magnetic?

It is thought that the word 'magnet' comes from the name of the ancient country of Magnesia which is now part of Turkey. In this region large numbers of black stones were found which had the power to draw pieces of iron to them. The black stone became known as lodestone or leading stone because of the way it could be used to find directions (see page 196). Today it is known as the mineral magnetite and it has been found in many countries.

Figure 16.1 Magnets are not only used to hold messages on fridge doors but a magnetic strip in the fridge door is also used to hold it closed.

The behaviour of magnets

Magnets can attract or repel other magnets and can attract any magnetic material even if it is not magnetised. When suspended from a thread, a bar magnet aligns itself in a north–south direction.

Figure 16.2 Magnetite is a naturally occurring magnet.

Non-magnetic materials, such as wood, paper, plastic and most metals, cannot be magnetised and so can do none of these things. Some, such as paper and water, can let the force of magnetism pass through them while other materials, such as a steel sheet, do not let the force of magnetism pass through them.

The strength of the magnetic force

At each end of a bar magnet is a place where the magnetic force is stronger than at other places in the magnet. These places where the magnetic force is strongest are called the **poles** of the magnet. The end of the magnet which points towards north when the magnet is free to move is called the north-seeking pole or north pole. At the other end of the magnet is the south-seeking pole or south pole.

When the north pole of one magnet is brought close to the south pole of another magnet that is free to move, the south pole moves towards the north pole. Similarly, a north pole is attracted to a south pole. However, two south poles repel each other, as do two north poles. These observations can be summarised by the phrase 'different poles attract, similar poles repel'.

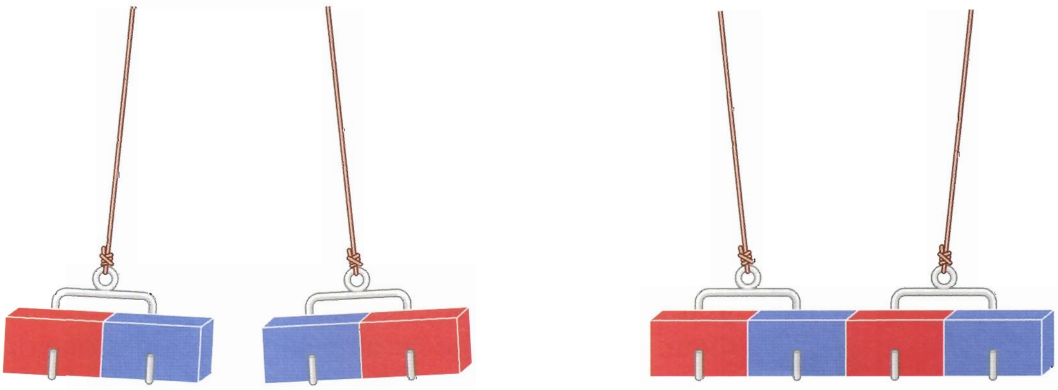


Figure 16.3 Different poles attract and similar poles repel

2 How do magnetic materials differ from non-magnetic materials in:
a) what they are made from
b) their properties?

If you bring a steel paper clip (which is not magnetised) towards either pole of a magnet you will feel the pull of the magnetic force become stronger as the paper clip gets closer to the pole. As you move the paper clip away again you will feel the pull of the magnet become weaker.

When a material that can show magnetic properties, such as a steel paper clip, is attracted to the end of a magnet it also becomes a magnet and can attract other magnetic materials to it. The paper clip has been made

3 What is the relationship between the distance from the magnet and the strength of the magnetic force?

4 Why do the two lower paper clips in Figure 16.4 join together?

5 A nail is magnetised by being in contact with one end of a magnet. Can it still attract magnetic materials to it when it is no longer in contact with the magnet? Explain your answer.

6 If three steel paper clips are attached in line to the bottom of a magnet the lowest paper clip is attached less strongly to the middle one than the middle paper clip is attached to the top one. A fourth paper clip cannot be added. Look at your answer to question 3 and explain why the paper clips behave in this way.

into a magnet by a process called **magnetic induction**. When the paper clip is moved away from the magnet it loses its magnetism.

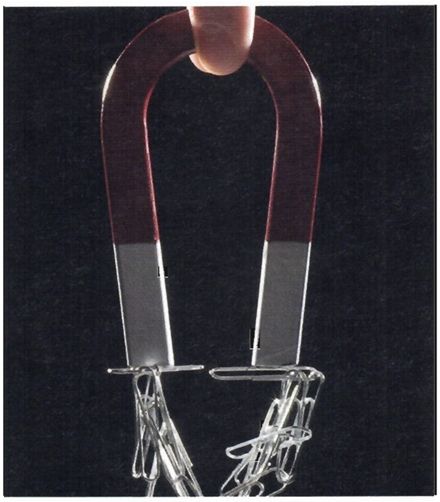


Figure 16.4 Paper clips attracted by a magnet are themselves magnetised.

Inside a magnet

Groups of particles from which a magnetic material is made form tiny regions called domains. Each **domain** behaves like a tiny magnet. If the domains are arranged at random (see Figure 16.5a) the material does not attract other magnetic materials to it although it can be attracted to a magnet. It also does not point north–south when it is free to move.

Magnetic domains can be made to arrange themselves in line. Then all their north poles face in one direction and all their south poles face in the opposite direction. This arrangement produces a north and a south pole in the material as a whole (see Figure 16.5b). When the material is in this condition it has been magnetised and so is now a magnet.

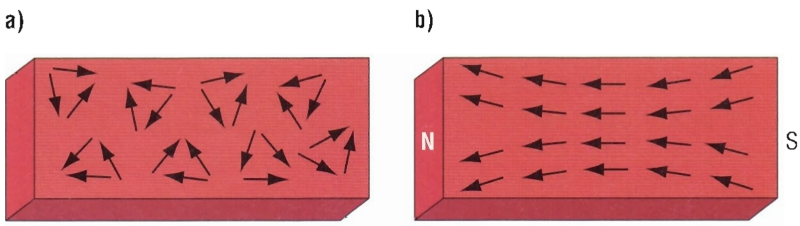


Figure 16.5 Domains in a magnetic material **a)** when it is not a magnetised material and **b)** when it is a magnet

7 If you cut a magnet in half does each half become a magnet? Explain your answer.

8 A piece of steel can be made into a magnet by repeatedly stroking it with a magnet as shown in Figure 16.6. How does this affect the domains?

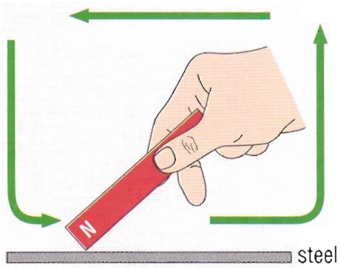


Figure 16.6

Some materials, such as steel, are magnetically 'hard' and once domains have been aligned they tend to stay aligned. Others, such as iron, are magnetically 'soft' and domains soon rotate again to random positions, so the material loses its magnetism.

The magnetic field

The region around a magnet in which the pull of the magnetic force acts on magnetic materials is called the **magnetic field**.

The field around a magnet can be shown by using a piece of card and iron filings. The card is laid over the magnet and the iron filings are sprinkled over the paper.

Each iron filing has such a small mass that it can be moved by the magnetic force of the magnet if the paper is gently tapped. The iron filings line up as shown in Figure 16.7. The pattern made by the iron filings is called the magnetic field pattern.

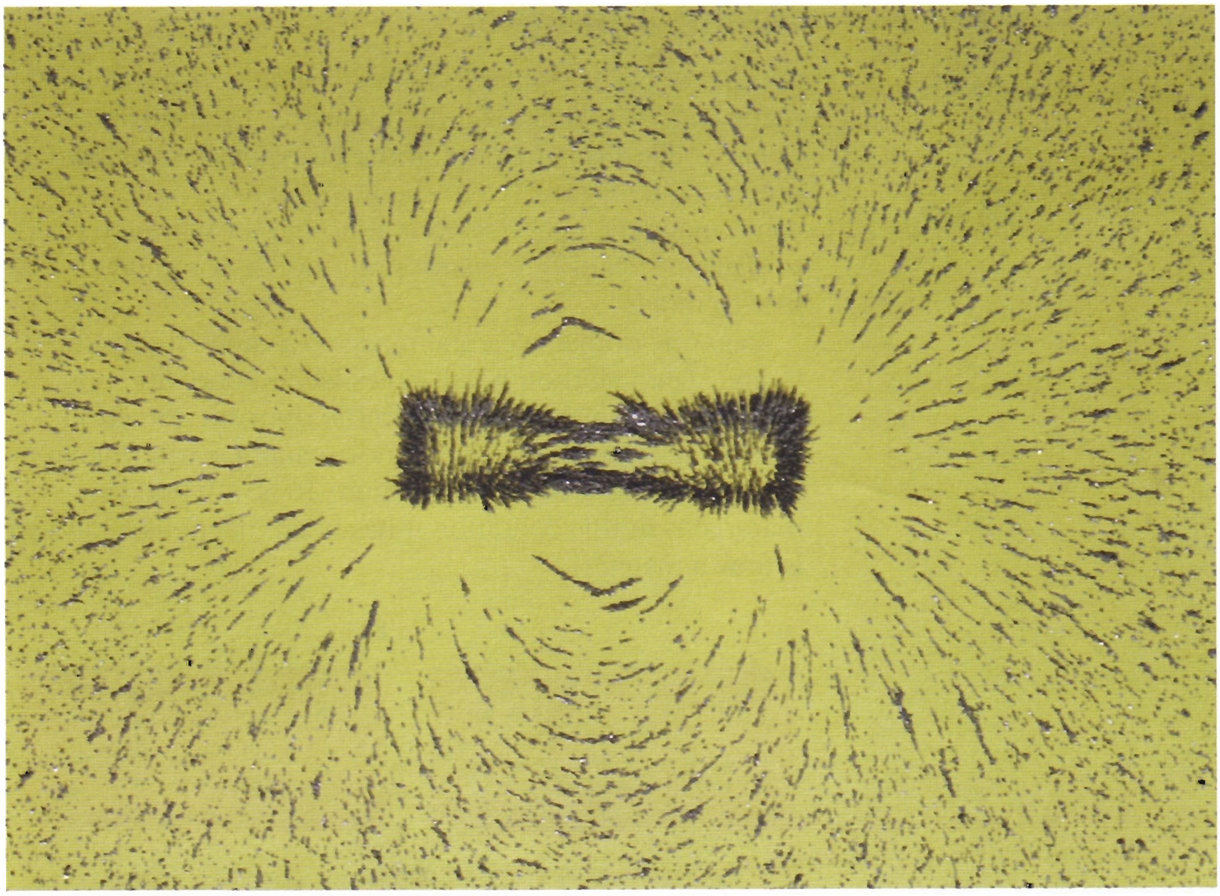


Figure 16.7 The magnetic field pattern of a bar magnet as shown by iron filings

The iron filings appear to form lines around the magnet. This phenomenon can be checked by using a plotting **compass** and a piece of paper and pencil. The magnet is placed in the centre of the paper and the plotting compass is placed on one side of the magnet close to its north pole. The north pole of the compass will point away from it. The position of the north pole of the compass is marked on the paper and the plotting compass is then moved so that its south pole is over the mark made on the paper. The position of the north pole is marked again with the plotting compass in the new position and the process is repeated until the plotting compass reaches the south pole of the magnet. The points marking the positions of the north pole of the compass are joined together by a line running from the north pole to the south pole of the magnet (see Figure 16.8a). This line represents one of the magnetic 'lines of force' forming the field pattern. Arrows should be drawn on the lines, pointing from the magnet's north pole to its south pole (see Figure 16.8b).

9 How does the information from the activity with the plotting compass compare with the field pattern produced by the iron filings?

10 Figure 16.9 shows iron filings spread out when in contact with the end of a bar magnet. Make a drawing of how you think the field lines are arranged all around the magnet.

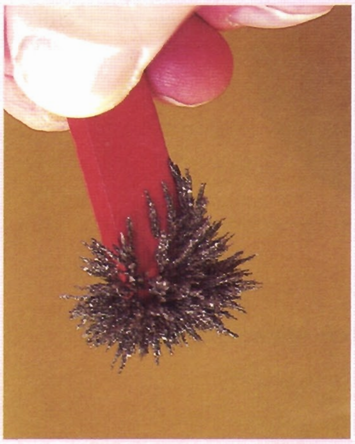


Figure 16.9

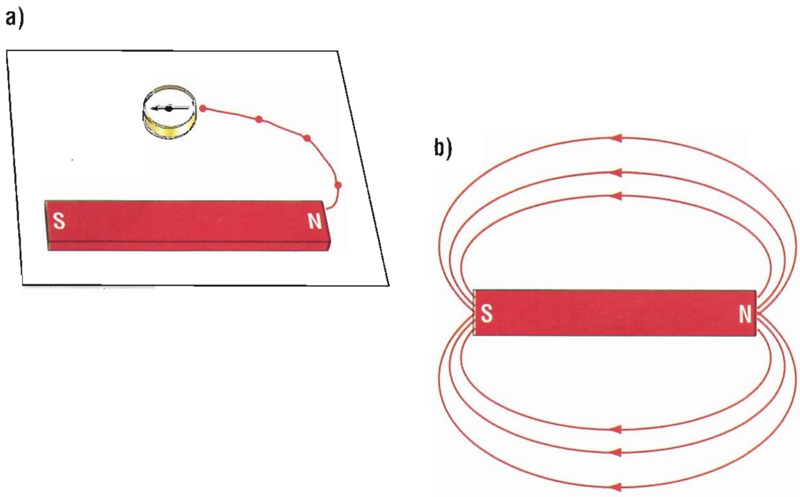


Figure 16.8 a) Drawing a magnetic line of force and **b)** the magnetic field pattern around a bar magnet

The Earth's magnetic field

At the centre of the Earth is the Earth's core. It is made from iron and nickel and is divided into two parts – the inner core made of solid metal and the outer core made of liquid metal. As the Earth spins the two parts of the core move at different speeds and this is thought to generate the magnetic field around the Earth and make the Earth seem to have a large bar magnet inside it.

The Earth spins on its axis which is an imaginary line that runs through the centre of the planet. The ends of the line are called the geographic North and South Poles. Their positions on the surface of the Earth are fixed.

Magnetic north – towards which the free north pole of a magnet points – is not at the same place as the geographic North Pole (see Figure 16.10) and it changes position slightly every year.

The magnetic north pole originally got its name because it is the place to which the north poles of bar magnets point. In reality it is the Earth's south magnetic pole because it attracts the north poles of magnets. Similarly the magnetic south pole is really the Earth's north magnetic pole because it attracts the south poles of bar magnets. However for most purposes the old, incorrect names for the magnetic poles are still used.

11 a) Look at the field pattern around the Earth in Figure 16.10. Which pole of the imaginary bar magnet inside the Earth coincides with magnetic north?

b) Copy Figure 16.10. On your diagram, draw a bar magnet inside the Earth and label its poles. Also label the position of the magnetic south pole on the Earth's surface.

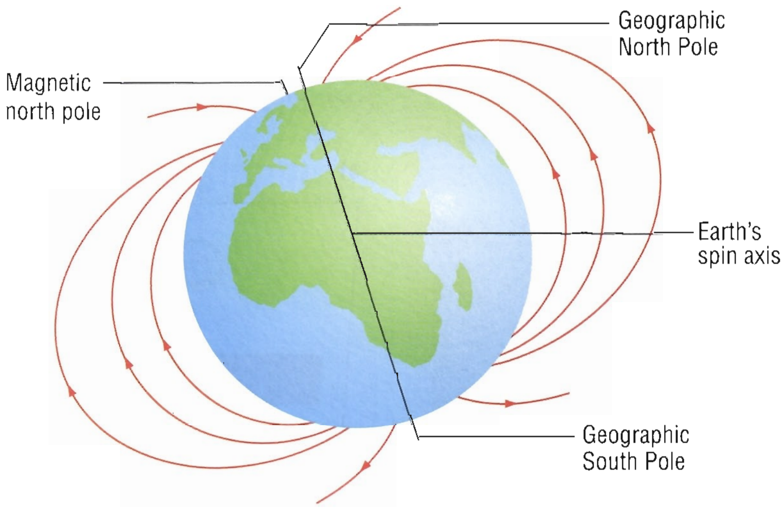


Figure 16.10 The Earth's geographic and magnetic poles do not coincide.

Early discoveries about magnetism

Probably the first use of a magnet in direction finding was in the practice of Feng Shui by the Ancient Chinese. They used a device called a luopan which contained a magnet to find a south-pointing direction. They then read off a scale around the magnet to decide on the final position of building foundations.

The first evidence of the magnet being studied scientifically for navigation is found in the writings of the Chinese scientist Shen Kuo (1031–1095). He performed experiments on magnetic needles, described how magnets pointed north and south and how other directions (east and west) could be found using a scale around the magnet. The knowledge of using magnetite for direction finding is believed to have slowly passed to other countries as they traded with one another.

Figure A A luopan

Figure B A 19th century mariner's compass.

Figure C William Gilbert

Petrus de Peregrinus (also known as Peter the Pilgrim) was a French engineer who lived in the 13th century. He experimented on the way magnets could attract and repel each other and how they could point north and south. He believed that the magnet pointed to the outer sphere of the heavens. Compasses at that time were made by floating a magnetic needle on water but Peregrinus showed that attaching the needle to a pivot made the compass easier to use.

William Gilbert (1544–1603) was an English scientist and doctor to Elizabeth I. He made many experiments on magnets and disproved beliefs such as 'garlic destroys magnetism' and 'rubbing a diamond on a piece of iron makes the iron into a magnet'.

Gilbert suspended a magnetic needle so that it could move both horizontally and vertically and discovered that the needle also dipped as it pointed north–south. He extended his investigation by using a model of the Earth made out of a sphere of lodestone (magnetite). He put a compass with a pivot at different places on the surface of his model Earth and showed that the dip varied with the position of the compass on the sphere, just as it did with compasses at different places on the surface of the Earth.

From this investigation Gilbert described the Earth as behaving as if it contained a huge magnet.

1 How do we know about the work of Shen Kuo?
2 How was knowledge of magnetism and direction finding spread to other parts of the world?

3 What evidence from the work of Peregrinus did Gilbert use when he did his scientific modelling?
4 Gilbert could have used two methods to show that rubbing iron with a diamond did not make a magnet. What do you think these were?
5 How do you think Gilbert tested whether garlic destroys magnetism?
6 When Gilbert saw that the magnet dipped as well as pointed north–south, what creative thought do you think entered his mind?
7 What further creative thought do you think Gilbert had to test his idea?
8 How did Gilbert's explanation of the reason for magnets pointing north–south differ from the explanation given by Peregrinus?

The link between magnetism and electricity

Hans Christian Oersted (1777–1851) was a Danish physicist who studied electricity. In one of his experiments he was passing an electric current along a wire from a battery when he noticed the movement of a compass needle which had been left near the wire. This chance observation led to many discoveries about how magnetism and electricity are linked together and has many modern applications.

When an electric current passes through a wire it generates a magnetic field around the wire. A compass can be placed at different positions on a card around the wire (see Figure 16.11) and the lines of force can be plotted.

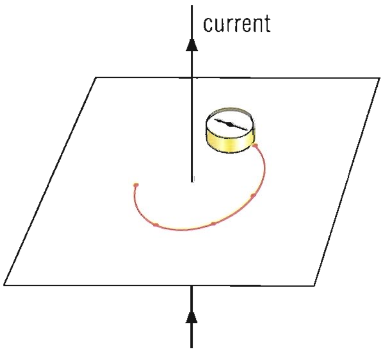


Figure 16.11 Plotting magnetic field lines around a current-carrying wire

When the current flows up through the card, the field shown in Figure 16.12a is produced. When the current flows down through the card, the field shown in Figure 16.12b is produced.

12 How are the magnetic fields in Figures 16.12a and b different?

13 How does the strength of a magnetic field around a wire vary?

14 Compare the magnetic field around a bar magnet (Figure 16.8b) with that produced by a current in a wire coil (see Figure 16.13).

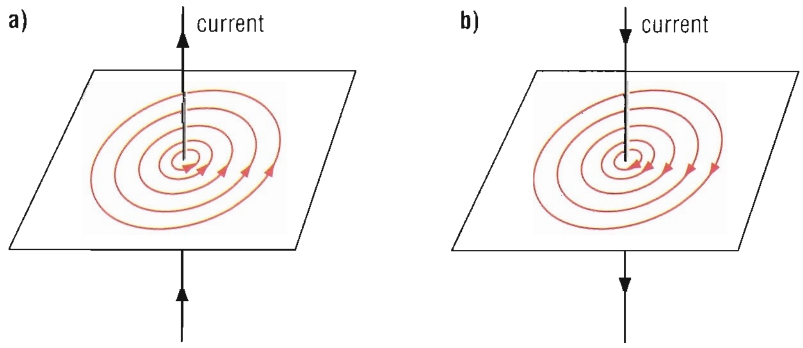


Figure 16.12 The magnetic field around a current-carrying wire

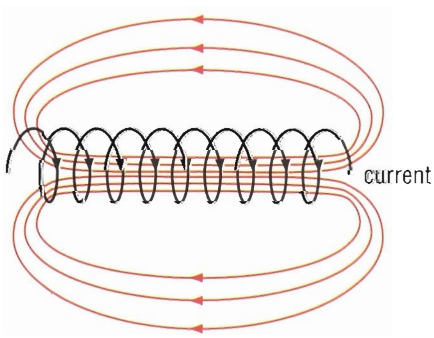


Figure 16.13 The magnetic field around a current-carrying coil

Lines of force on diagrams of magnetic fields show not only the direction of the field as given by a plotting compass but also the strength of the field in different places. The lines of force are close together where the field is strong and further apart where the field is weaker.

If the wire is made into a coil and connected into a circuit, a magnetic field is produced around the coil as shown in Figure 16.13.

If a piece of steel is placed inside the wire coil and the current is switched on, the magnetism of the coil and the steel is stronger than that of the coil alone. The current flowing through the coil induces magnetism in the steel. When the current is switched off the steel keeps some of the magnetism it acquired because it is magnetically hard (see page 194).

If a piece of iron is placed inside the coil it makes an even stronger magnet when the current is switched on than the steel did. When the current is switched off the iron loses its magnetism completely because it is magnetically soft (see page 194).

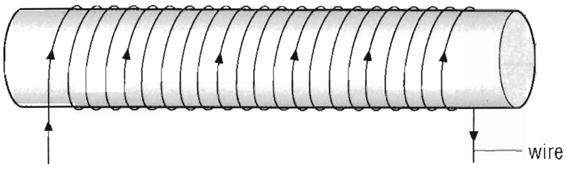


Figure 16.14 A steel bar within a coil

The electromagnet

An electromagnet is made from a coil of wire surrounding a piece of iron. When a current flows through the coil, magnetism is induced in the iron and the coil and iron form a strong electromagnet. When the current is switched off, the electromagnet loses its magnetism completely and, straight away. This device, which can instantly become a magnet and then instantly lose its magnetism, has many uses. For example, a large electromagnet is used in a scrap yard to move the steel bodies of cars (see Figure 16.15).

15 Describe how you think an electromagnet can be used to make a stack of scrapped cars three cars high.

Figure 16.15 An electromagnet in use in a scrap yard

The electric bell

Look at Figure 16.16 and see if you can work out the path the current takes through the circuit when the switch is pushed.

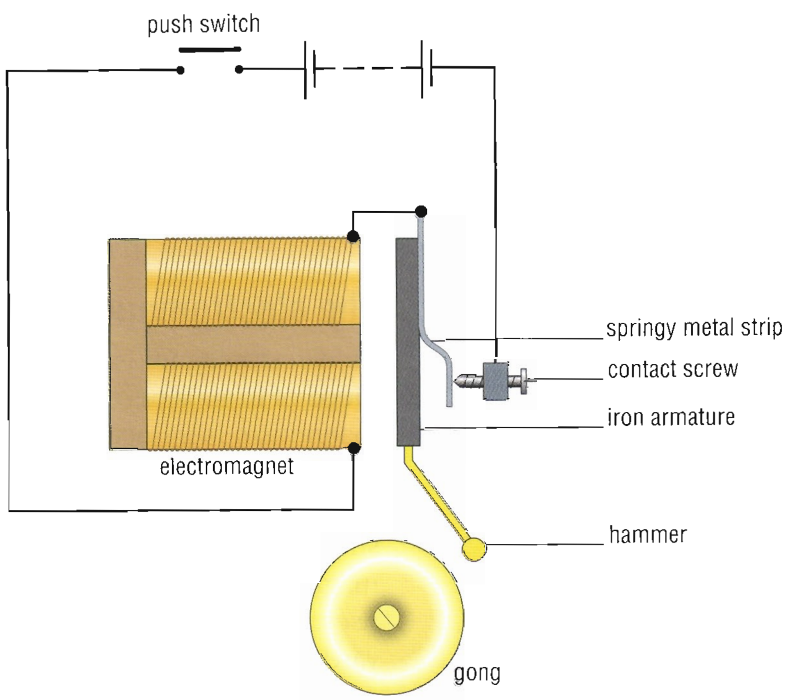


Figure 16.16 The circuit of an electric bell

16 Describe the changes that take place in the springy metal strip holding the armature when the current:

a) flows

b) stops flowing.

Use the term 'strain force' in your description.

When the switch is pushed the current passes through the coil and the electromagnet pulls the armature to it. This makes the hammer strike the gong. When the armature is pulled to the electromagnet a gap develops between the springy metal strip and the contact screw and the circuit is broken. The current stops flowing and the electromagnet loses its magnetism. This makes the armature swing back to its original position. The springy metal strip and the contact screw now touch again and complete the circuit so the armature is pulled to the electromagnet once more. The bell is made to ring by the repeated beating of the hammer until the push switch is released.

SUMMARY

- Magnetic materials are attracted by a magnet; non-magnetic materials are not (*see pages 191–192*).
- A magnet can attract or repel another magnet (*see page 192*).
- A bar magnet aligns itself in a north–south direction when it is free to move (*see page 191*).
- A magnet has a north-seeking pole and a south-seeking pole (*see page 192*).
- A magnet can be made by induction (*see page 193*).
- A magnetic field exists around a magnet (*see page 194*).
- The Earth has a magnetic field (*see pages 195–196*).
- A wire with an electric current passing through it has a magnetic field around it (*see page 198*).
- An electromagnet is a magnet whose magnetism can be switched on and off by switching a current on and off (*see page 199*).

End of chapter questions

1 Why do magnets line up in a north–south direction?

2 Assess the importance of magnetism in the working of electrical devices in the home.

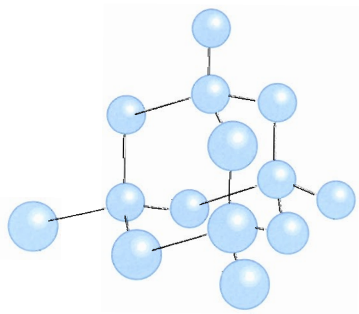
Appendix

You may sometimes see a chemical formula or a model of a molecule on a science show on television or in a science fiction film. In this section there is a simple introduction to formulae and molecules to help you tie them in with the work you have done in chemistry.

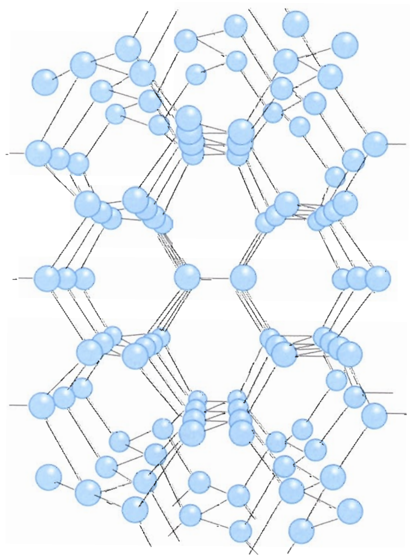
When a word equation is changed into one where chemical **formulae** are used it becomes a chemical equation.

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

Figure A Chemical formulae in a chemical equation



small part of the structure



larger part of the structure

Figure B The molecular structure of diamond, showing the arrangement of carbon atoms

Chemical formulae

You may have come across the term **chemical formula** and seen a jumble of letters and numbers to describe a substance. You will learn to use chemical formulae in IGCSE work but a simple explanation is given here to show how work you have done in this book relates to a simple yet detailed way to explain the structure of matter and how matter changes during chemical reactions.

In Chapter 8 the particle theory states that everything is made from particles. In Chapter 9 the particles are identified as atoms and molecules and you learnt that each element is made from its own special atoms and has been given a name and a chemical symbol. In Chapter 10 the word equation is introduced to show how a chemical reaction can be written down quickly and easily, but chemists have gone a stage further.

They have discovered how the atoms join together to make a compound. In some compounds one atom of an element joins with one atom of another. For example, in common salt one atom of sodium joins with one atom of chlorine to make sodium chloride. This can be written as the chemical formula NaCl.

In other compounds an element may join with two or more atoms of another element. For example, in carbon dioxide one atom of carbon is joined to two atoms of oxygen. The number 2 is written as a subscript after the symbol for oxygen so the chemical formula for carbon dioxide is written as CO_2.

Chemists have also discovered that when an element is present on its own its atoms may not be single but may be joined together in pairs to form a molecule. Oxygen is an example of a substance made from a molecule of two atoms of one element. Its formula is O_2. Again a 2 is written as a subscript. In fact the numbers relating to the numbers of atoms in a molecule are always written as a subscript.

Some molecules have three or more elements in them and there may be a different number of atoms of each element. For example, in a molecule of sulfuric acid there are two atoms of hydrogen, one atom of sulfur and four atoms of oxygen. The formula of sulfuric acid is H_2SO_4. Note that where there is more than one atom of the element, the number of atoms of that element is shown as a subscript after the symbol for the element.

The chemical equation allows the chemist to write down information about the reaction even more quickly than

1 The equation in Figure B describes a reaction that takes place in plants.
   a) Name the process taking place.
   b) Name the reactants and the products.

2 Write the formula for:
   a) sodium hydroxide (it has one atom each of sodium, oxygen and hydrogen)
   b) sodium nitrate (it has one atom of sodium, one atom of nitrogen and three atoms of oxygen)
   c) sodium sulfate (it has two atoms of sodium, one atom of sulfur and four atoms of oxygen).

3 Sometimes the name of a compound gives a clue to its formula. What do you think is the formula of:
   a) sulfur dioxide
   b) carbon monoxide?

a word equation. It also allows more information to be given about how the atoms of the elements combine. For example, the reaction between calcium and chlorine can be written as a word equation as:

calcium + chlorine → calcium chloride

and as a symbol equation as:

$$Ca + Cl_2 \rightarrow CaCl_2$$

and the reaction between copper oxide and sulfuric acid can be written as a word equation as:

copper oxide + sulfuric acid → copper sulfate + water

and as a symbol equation as:

$$CuO + H_2SO_4 \rightarrow CuSO_4 + H_2O$$

Notice that the number of atoms on the left-hand side of the equation balances the number on the right and so describes the movement of atoms during the reaction. When chemists construct chemical equations they must make sure that the same number of atoms occur on both sides of the equation. The reason for this is due to the law of conservation of mass which has been built up from the results of many investigations on chemical reactions. It states that when substances take part in a chemical reaction matter is neither created nor destroyed and the mass of the reactants is always the same as the mass of the products. Here are some examples of how they do it.

To make the number of atoms balance, other numbers may have to be added in front of one or more of the formulae for the reactants and products. For example:

calcium + oxygen → calcium oxide

$$Ca + O_2 \rightarrow CaO$$

In this form there are two atoms of oxygen on the left and only one on the right. The equation is balanced by adding a '2' in front of the CaO to balance the number of oxygen atoms and by adding a '2' in front of the Ca to balance the number of calcium atoms. So the balanced equation is:

$$2Ca + O_2 \rightarrow 2CaO$$

When balancing equations, the formulae of the reactants and products must not be altered. For example:

sodium + chlorine → sodium chloride

$$Na + Cl_2 \rightarrow NaCl$$

4 Write the word equations for these symbol equations and then balance the symbol equations.

a) $K + H_2O \rightarrow KOH + H_2$

b) $Mg + O_2 \rightarrow MgO$

The equation is not balanced and, although it could be balanced by writing $NaCl_2$, this compound is not formed and the equation would be incorrect. The equation can be balanced by making it:

$$2Na \quad + \quad Cl_2 \quad \rightarrow \quad 2NaCl$$

Molecular models

Once scientists became convinced that molecules were made from groups of atoms, they started thinking about how the atoms were linked together. Three hundred years ago some scientists thought that atoms were linked by hooks and eyes, as in some types of clothing. Other scientists thought that the atoms were glued together. In the twentieth century the links were known as bonds and more details of the structure of the atom became known. (You will learn more about this in *Cambridge Checkpoint Science 3*.) This allowed calculations to be made on the position of the bonds and from this the angles between the bonds were worked out. Using this knowledge chemists were then able to build three-dimensional models of the molecules using balls for atoms and short rods for bonds.

For discussion

A water molecule is made from one oxygen atom and two hydrogen atoms. The angle between the two bonds is 104°. What everyday materials could you use to make a model of it and what piece of equipment will you need to make it?

How many model atoms and bonds would you need to make a model of the arrangement of carbon atoms in the diamond in Figure B? What materials would you use?

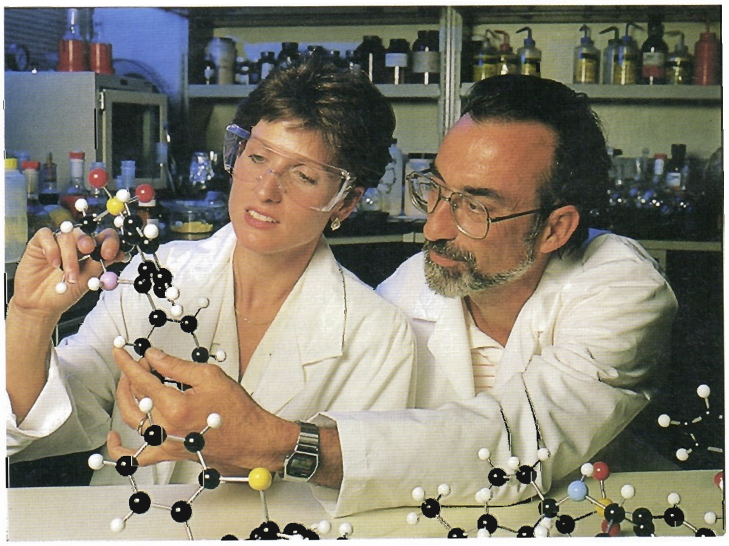


Figure C By studying reactions carefully, the structure of large molecules can be discovered.

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